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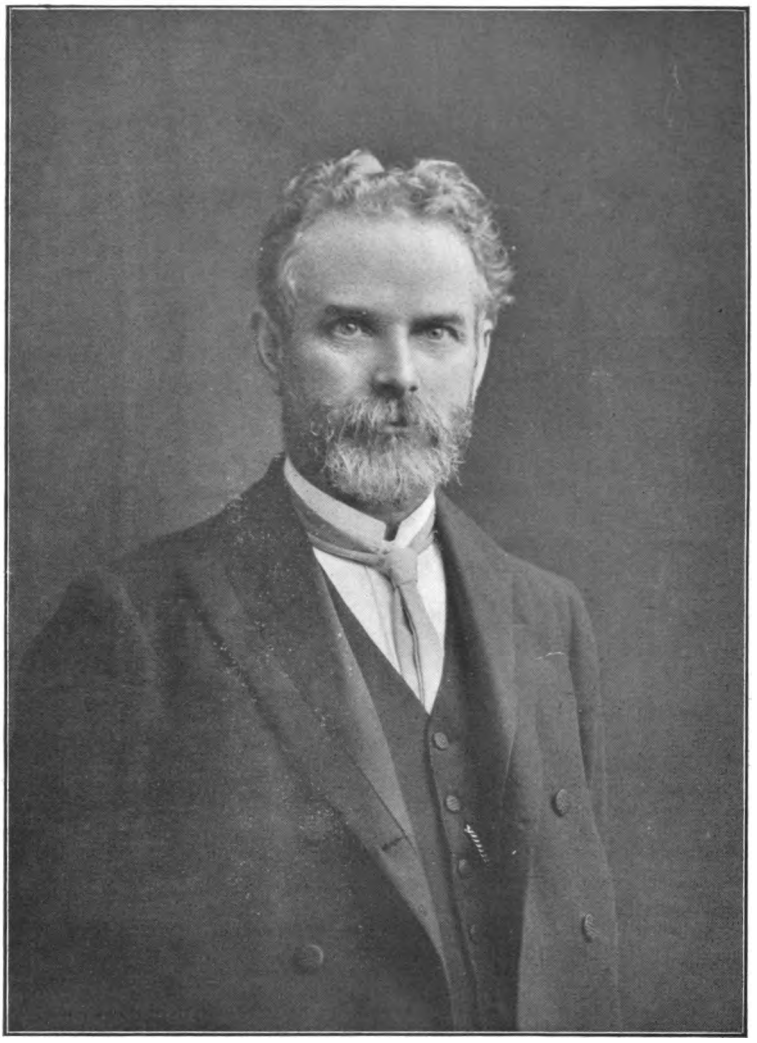

S Wolfenden

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PIOENA

A Treatise on the Art of Pianoforte Construction

By

S. Wolfenden

TECHNICAL EXPERT TO THE ORCHESTRELLE COMPANY
MANUFACTURERS OF THE WEBER PIANOFORTE

Illustrated

PRINTED FOR THE AUTHOR BY
UNWIN BROTHERS, LTD., 27 PILGRIM
STREET, LONDON, & WOKING, SURREY
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PREFACE

THE author of this treatise has for more than half a century been an ardent student of the subjects of which he writes, and for many years has been employed as expert in leading pianoforte manufactories. Circumstances have permitted him to hold under observation for long periods instruments produced by renowned makers of this and other countries, thus enabling him to form judgments, not only as to the causes of satisfactory musical qualities in new pianos, but also as to the causes which contribute to the stability of those qualities.

No longer subject to the full stress of business, it seems fitting that leisure should be used to convey to others the knowledge of principles, and methods of their application, which by study and observation during a long and strenuous life he has been able to acquire.

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1916.

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CHAPTER I

INTRODUCTORY

It is not intended to give, in this work, such elementary and detailed instructions as would encourage an amateur mechanical enthusiast to attempt the construction of a pianoforte.

What *is* purposed is to supply for pianoforte makers, particularly the ambitious young men in our ranks, a knowledge of principles which cannot be obtained in the factory, the absence of which often prevents men of great natural ability making the best use of their powers.

It is not easy to assign a cause for the fact but the fact remains, that not only has there been in this country sad lack of technical education (except for the favoured few) but that for some reason we have not been ashamed of the lack but rather disposed to pride ourselves upon it, to imply that a knowledge of principles is opposed to practical efficiency.

There is, however, good reason to believe that a disposition is rapidly growing to amend this condition of things, and add to our unquestionably great executive abilities, that knowledge of scientific principles which will lead to the best application of our industry.

For the education of the pianoforte maker there are, as yet, even fewer facilities than are provided for the study of any other art. The apprentice can be trained to competency, as a workman, at one or more of the branches into which the business is divided, but for his instruction in the principles which underlie the operations, there are neither means nor opportunities.

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The technical literature is scanty, and what does exist is often very remote from the actual needs. To simplify the difficult teaching of the scientists, so as to be easily intelligible and ready for application to actual work, is the aim of this book.

I shall not need to go deeply into the general subject of acoustics, but shall limit myself to those aspects of the science which are directly connected with the above purpose. It cannot, however, be denied that a close study of that subject would be of advantage to every pianoforte maker.

There are classes open to all, on favourable conditions, at the various institutes and polytechnics, and any who are able, are advised to take a course in "Sound" at one of these, and while learning much which will not seem to have a direct bearing on the daily work, to give special attention to those parts of the teaching which do have a bearing. Also there are standard works (expensive truly, but to be had at the libraries), and among these may be mentioned Tyndall's lectures on "Sound," Helmholtz on "The Sensations of Tone," Sedley Taylor on "Sound and Music." There are many others, but some of them are so loaded with mathematical formulæ as to be unintelligible to the ordinary reader.

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CHAPTER II

SCALE CALCULATION

The Metric Rule

For all the scaling calculations in this work the metric system of measurement will be used.

It is to be regretted that in this country and in the United States, this system has not been adopted.

Its advantages become very obvious, when dimensions have to be multiplied, divided, or adjusted to proportion, all the divisions of this rule being decimal.

The "Metre," which is the standard of the system, equals 39·37079 English inches, a very near approximation to $39\frac{3}{8}$ in.

This length is divided into 100 centimetres, usually expressed thus: cm.; and each of these is subdivided into 10 millimetres expressed thus: mm.; so that 1000 mm. equal 1 metre.

The millimetre is equal to a trace more than $\frac{1}{25}$ of an inch, and the smallness of this has a beneficial effect on the mind and working habits.

Many English rules are not marked with closer divisions than $\frac{1}{8}$ of an inch, and a workman grows to regard this as a small quantity, and thus his sense of accuracy is impaired.

The only adaptation of the English rule which renders such calculations as are used in scaling fairly easy, is to divide the inches decimally and express all dimensions in inches and decimal parts; but even if this is done, the full metric system is much more convenient.

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The Slide Rule

Every young pianoforte maker who desires to qualify as a general expert, should procure a slide rule and make himself fairly proficient in its use. It is a simple calculating machine by which arithmetical operations (to most people difficult and tiresome) can be performed with ease, and with so close an approximation to accuracy as to suffice for practical purposes. It is marvellous that so valuable a tool should be so little known and used.

By it, all forms of ordinary calculation except addition and subtraction can be directly worked.

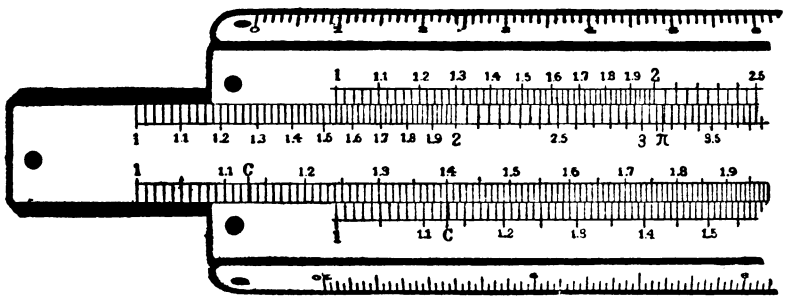

Fig. 1.

The illustration (Fig. 1) shows the ordinary pattern, from which however variations are sometimes made for special purposes.

The rule, 10 in. long with celluloid facings, can be purchased from mathematical instrument makers from 5s. upwards. Detailed directions for use are unnecessary here, seeing that books of instructions are sold at the same shops.

Nearly all the calculations which follow are slide-rule readings.

Some pianoforte makers are unwilling to incur the trouble and cost of properly calculated and drawn scale designs.

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The more usual way is to copy instruments of suitable dimensions, which seem to possess pleasing qualities.

Naturally this method of procedure not only reproduces such errors of design as there may be in the instruments copied, but probably introduces others.

Surely it is real economy, when setting out to make a new style of piano (even of cheap grade) which it is hoped to sell in large numbers, to use every endeavour, at the outset, that the result shall be as successful as care and knowledge can ensure.

There is no reason why even inexpensive pianos should not be true musical instruments, satisfying educated tastes. The difference between some of the lower grades and the highest, is due less to the relative cost of materials and workmanship, than to initial errors of design.

There are many pianos on the market which would not be greatly improved, however expensively they might be made.

When stringed instruments were first operated with key mechanism, the public taste was already adjusted to the thin and light tone of harps, lutes, dulcimers, and guitars, and naturally the clavichords, virginals, spinets, and harpsichords (succeeded in their turn by the early grand and square pianofortes) followed this taste.

Makers, players, and hearers, all seem to have been delighted with these productions, and would hardly have appreciated the full, round tone of a high-class modern concert grand, had it suddenly been displayed before them.

But quite apart from questions of musical taste, and other practical questions of strain-bearing structure, of actions and hammers, there was one outstanding reason why any approach to the tone which satisfies the public in 1916 was impossible prior to, say, 1820. There was no *steel* wire available for the stringing of pianos; that which was used, was iron for the

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tenor and treble portions, with brass and copper for the bass part.

So soft was this wire, that it was easily wrapped around the wrest pins by the fingers of the stringer, and made to hold by crossing one-half of the many coils over the end, without a drill-hole to retain it.

Not only did the low tenacity of the iron wire prevent the use of tensions adequate to the production of full, round, brilliant tone, but it also prevented stability of the tuning; a few blows of the hammer would seriously affect the pitch of a note.

It is not too much to say, that the improvements in the tenacity and elasticity of steel wire, made during the last century, have rendered possible the modern piano.

While there is good reason to believe that in very early times thin threads of metal were produced (indeed, such remain to testify to the fact), it seems that there was nothing like the present *drawing* process in existence prior to 1350, when the wire-smiths of Germany commenced to draw wire through holes in steel plates to make it circular. Previously, their practice had been merely to hand shape, by the use of files, &c., filaments cut from the edges of hammered plates. But soon they found the drawing method available, not only for the finishing, but for the actual production of wires from comparatively thick rods, by successive reductions in diameter, with corresponding extensions in length.

When wire began to be used as strings for musical instruments, that produced in German mills was almost exclusively used, and although steel wire was made in Wales in 1735, the German *iron* does not seem to have been really displaced, until Brockedon, in 1819, introduced his invention for drawing wire through holes in diamonds and rubies.

It is obvious that while the wire-drawer had no better tool than a tapered hole in a plate made of such steel as was then obtainable, only comparatively soft metals could be treated; but with the invention

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mentioned above, began a succession of improvements, which result in a present-day cast steel hard drawn wire of a tenacity (for small gauges) equal to 500 lbs. to 600 lbs. per sq. mm.

The sectional area of No. 20 of the music wire gauge, is a near approximation to a square millimetre.

It is interesting to watch the growth of this remarkable strength, and I have extracted from the record of one high-class and expensive wire, the following :—

				Diameter.	Breaking Strain.
1867	No. 13	...	...	0·770 mm.	226 lbs.
1873	"	...	...	" "	232 "
1876	"	...	...	" "	265 "
1884	"	...	...	" "	275 "
1893	"	...	...	" "	325 "

This advance is 44 per cent for the twenty-six years. These samples were, of course, specially drawn for competition, and commercial wire of this gauge cannot *even now* be trusted to reach above 260 lbs. breaking strain. Were pianoforte makers, however, to use their conjoint influence, there is no doubt that even further progress could be made and advantageously used.

The writer has personally tested for tenacity many samples—13, 13½, and 14 gauge—and while some have reached even 270 lbs. for No. 13, others have fallen ridiculously low.

One most remarkable experience may be recorded.

A new make of steel wire was offered, and tests were made at two separate dates and from separate samples. The result of the first was, No. 13, 270 lbs. breaking strain; No. 14, 276 lbs. The tenacity of No. 13 being 270 lbs., that of No. 14 should have been about 306 lbs., so here was ground for suspicion, which caused the second trial with other samples. This worked out: No. 13, 259 lbs. breaking strain; No. 14, 200½ lbs. In this case 14 should have broken at 294 lbs., but actually fell 93 lbs. below.

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A calculation of my own makes the gross strain upon the small square pianos made about 1780, somewhere in the region of $3\frac{3}{4}$ tons. It is said that in 1840 a grand piano had a total strain of 6 tons.

The late A. J. Hipkins stated that Broadwood's normal tension in 1862 was 150 lbs. for each steel string, this (assuming the equality of the bass notes) gives us 17 tons. The present average ranges between 18 and 21 tons.

The truth of the proposition seems now sufficiently established, viz., that the difference between the modern piano and that of ancient times, is just the measure of the difference between an iron wire of low tenacity, and one of cast steel, with a tensile strength $3\frac{1}{2}$ times greater. This is the determining factor to which all other differences have been adjusted.

The enormous tenacity is not due solely to the material used.

In its unworked state the average tenacity of cast steel has been found to be 106,200 lbs. per square inch, whereas the same authorities give for the metal when drawn into music wire, 320,000 lbs. rather more than an increase of three times, and a very close approximation to 500 lbs. per sq. mm.

It will be interesting to trace the processes by which such a remarkable result is reached. The billet of steel is first passed through a rolling mill, and by repeated rollings is formed into roughly round rods of suitable dimensions for the drawing process.

It is then drawn through the series of holes, each one decreasing its diameter and increasing its length. During this operation it has to be frequently annealed, because of the increase of hardness, and the drawing goes on until the required gauge is attained.

A recognition of these facts will help us to understand why the finer gauges have a higher proportionate breaking strain than the larger ones.

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A structural change takes place in the metal during drawing.

Cast steel is (to begin with) crystalline in structure, and easily broken by cross strain, but as wire, it becomes very fibrous. This is manifest in an endeavour to break it, by grasping in pliers and racking backwards and forwards. It will frequently part with difficulty and the fracture is jagged, and often (near the actual fracture) the wire splits lengthwise.

Examination by the microscope shows that the structure is not the same throughout the thickness. There is a thin skin which does not break in the same way as the interior. The shape of the fracture produced by longitudinal strain is very peculiar. First, at the place of fracture there is a reduction of thickness extending from the point of division for, say, a length equal to twice the diameter on each side, and at the thinnest part reducing the diameter by about 25 per cent. The skin shows a silver-grey fracture, but the inner portion is darker and more coarsely ruptured. The most singular feature is, that the inner part does not separate on the same line as the skin, a sort of rough cup and ball shape is formed, the one end being pitted, and the other drawn out.

Of course, the shape of the cup and ball is not at all regular but that aspect is suggested to the naked eye.

The stretch of first-class wire is not of large amount. When in testing a sufficient strain has been put upon it to overcome the curled form, due to the way it has to be packed, and any slip there may be at the points of attachment, no very sensible elongation takes place, until just before the breaking-point is reached, when a quick run down of the indicator occurs, sometimes of several lbs., followed by the snap. In some few cases I have found this preparatory run down, very small indeed, and this I regard as creditable.

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Very frequently, even in the same make of wire, the nominal dimensions are not true to standard. The ordinary slit gauge does not reveal this, unless the discrepancy is large, but the micrometer shows it very distinctly.

Also, the wire is often *not quite round.* This was at one time a very grave defect, and while great improvement has been made, it remains with us, and if (when the string is in position) the difference is not parallel to the axis, *but twisted*, it may perhaps cause that troublesome tone defect called falseness. Of this more anon, when we reach the subject of overtones.

Music Wire Gauges

Who graded the English gauge, and what principle was in view in the grading, I have not been able to discover.

It does not conform to any of the older general gauges, and is not quite consistent with itself, in that the steps are not quite regular. Still, the errors fairly compensate each other, and give us an average so nearly in the proportion as 16 : 15, for the whole numbers, that this ratio has been accepted as a working rule. If accidental, this proportion is a very happy accident.

There is now in use on the Continent, a music wire gauge called the New Westphalia gauge, which advances, for the numbers up to 22, in very nearly that proportion; after No. 22 the steps are much larger.

These larger steps need not now concern us, being beyond those in use, except as the cores of covered strings. The grading of this gauge is in thousandths of a millimetre, *and is quite regular.* For all the following calculations of string dimensions, this gauge is used.

Fig. 2 is a scale showing the length of each whole number between 14 and 20 inclusive, which is tensionally equal to 30·5 cm. in length of No. 14.

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The left-hand side is according to the New Westphalia gauge, while that on the right conforms to the latest statement of English diameters available.

Using the former, we see that if a string of No. 14 wire 30·5 cm. in length is brought to a desired pitch, by a certain stretching force, one of No. 15 to be tuned to the same pitch at the same tension, will measure 28·8 cm. in length, and correspondingly for any other diameter.

These proportions are ascertained arithmetically, by multiplying a given length by a given diameter and dividing the result by another diameter.

Thus No. 14, 30·5 cm. × 0·825 mm. = 252, ÷ 0·875 (the diameter of No. 15) gives length 28·8 cm. The same results are obtained if the square roots of sectional areas are used instead of the diameters.

A geometric method of working this problem is shown in Fig. 3.

Draw a straight line *ab* and from *a*, another line *ac* at any convenient angle.

On both these lines, mark a given length, say 30·5 cm. measured from *a*, unite these marks by a line *de*.

Then multiply the diameters by 200. Measure a corresponding length, which for No.

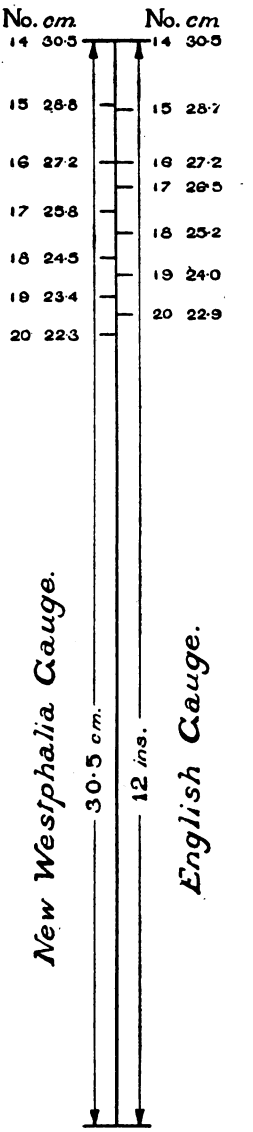

FIG. 2.

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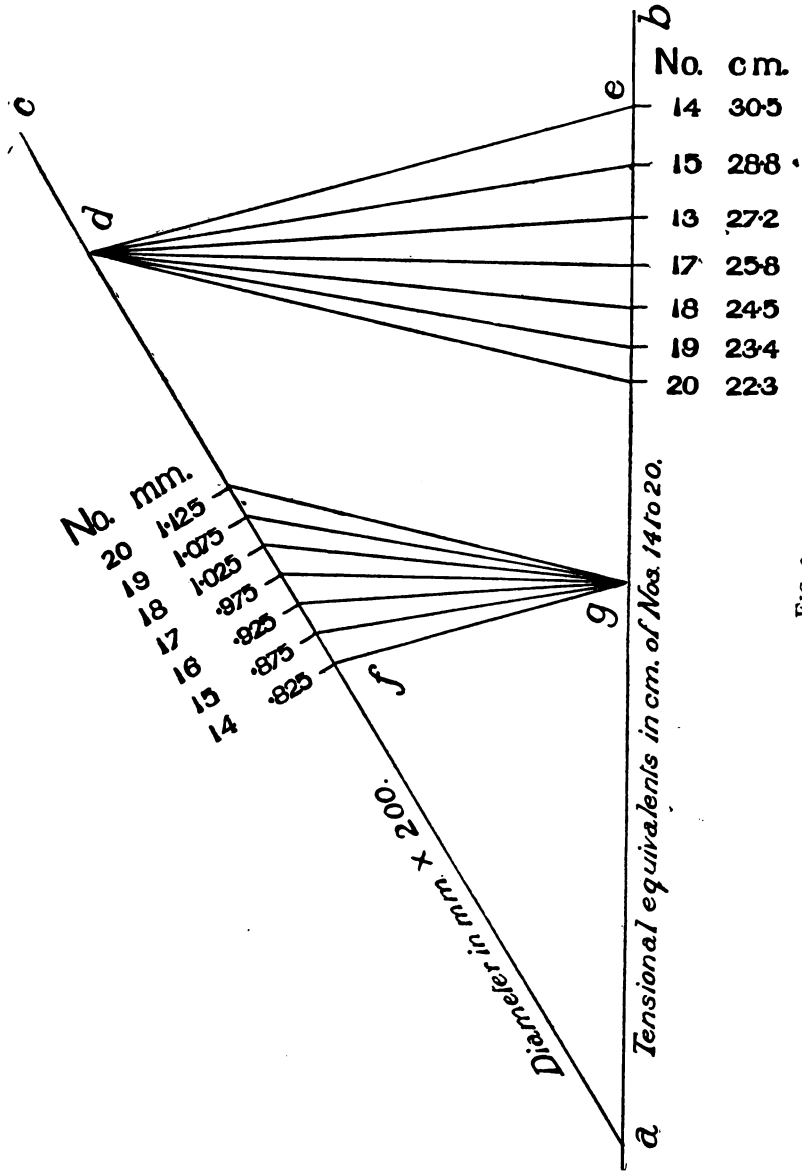

FIG. 3.

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14 is 16·5 cm., from *a* on both lines and unite *fg*.

On *ac* mark the remaining multiplied diameters, and rule lines to the point where the line which represents No. 14 cuts *ab*.

From the point *d*, on *ac* draw lines exactly parallel with those which represent the diameters, and the length equivalents are shown on *ab*.

Relative Tensile Strengths, etc.

We have now to consider the relative tensile strengths of the various thicknesses.

These vary directly as the sectional area. The sectional area is as 78·5 : 100; thus, No. 17½, with a diameter of 1·00 mm., has a sectional area of 0·785 mm., that being the ratio of the difference between circular and square area.

To obtain the circular area of a given diameter, square the number of the diameter and divide the result by 1·275.

On some modern slide rules an indicator is provided marked C, to enable scales A and B to be easily set in this ratio, which brings 785 on B under 10 on A. Thus set, if diameters are read on D (the lowest of the rows of figures), the corresponding circular areas are on B above.

To extract the square roots of the areas, read areas on A to roots on D.

The standard given is the theoretic one, but the larger wires will not hold up to the relative strength of the smaller ones. This seems to be due to the fact that the finer sizes undergo more drawings and annealings than the coarser ones, and the skin (which shows so distinctly in fracture experiments) becomes proportionally thicker.

No reliable ratio seems to be possible for this reduction of strength, and the Table (No. I) which follows, assumes equality upon the reasonable average of 260 lbs. for No. 13. The fact is not important to

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the pianoforte maker, because his strains are only critical at the very top notes, and the safety margin increases as the scale descends, because the tension required per string is the same throughout, except in the portion in which covered strings are used.

TABLE No. I.

Wire Gauge Number.	Diameter. (mm.)	Area.	Breaking Strain in Lbs. Theoretic.	Tension in Lbs. to produce Top C.	Margin of Safety in Lbs. Theoretic.
No. 13	0·775	0·471	260	163	97
,, 13½	0·800	0·502	277	173	104
,, 14	0·825	0·533	294	183½	110½
,, 14½	0·850	0·568	314	196	118
,, 15	0·875	0·601	332	207	125
,, 15½	0·900	0·635	350	219	131
,, 16	0·925	0·671	370	—	—
,, 16½	0·950	0·708	391	—	—
,, 17	0·975	0·747	412	—	—
,, 17½	1·000	0·785	433	—	—
,, 18	1·025	0·826	456	—	—
,, 18½	1·050	0·867	477	—	—
,, 19	1·075	0 907	501	—	—
,, 19½	1·100	0·950	525	—	—
,, 20	1·125	0·994	547	—	—
,, 20½	1·150	1·039	573	—	—
,, 21	1·175	1·082	598	—	—
,, 21½	1·200	1·131	625	—	—
,, 22	1·225	1·180	651	—	—
,, 23	1·300	1·328	732	—	—
,, 24	1·400	1·540	848	—	—
,, 25	1·500	1·770	974	—	—

Table No. I shows the English gauge number, the corresponding New Westphalia mm. diameter, the area of cross-section, the *theoretic* breaking strain for each gauge and half gauge, from 13 to 25, and, additionally, the tensions necessary to produce top C with various stringings, supposing it to be of such a length as to come to its pitch at 163 lbs. if strung with No. 13, with the corresponding margins of safety.

The writer supposes the information in the additional columns will be useful for he has found much confusion of thought upon the subject.

The numbers given in the Tables being slide-rule readings, the small fractions are ignored in most of the

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multiplications, as representing quantities far too minute to be of practical importance.

Should it be desired to reduce the theoretic margin to an approximate actual, the nearest approach to an average result of tests is: Add to the breaking strain of each half gauge $13\frac{3}{4}$ lbs., thus:—

	Breaking Strain.					Tension.	Margin.
	lbs.		lbs.		lbs.	lbs.	lbs.
No. 13	260		—		—	163	97
„ $13\frac{1}{2}$	260	+	$13\frac{3}{4}$	=	$273\frac{3}{4}$	− 173	$100\frac{3}{4}$
„ 14	$273\frac{3}{4}$	+	$13\frac{3}{4}$	=	$287\frac{1}{2}$	− $183\frac{1}{2}$	104
„ $14\frac{1}{2}$	$287\frac{1}{2}$	+	$13\frac{3}{4}$	=	$301\frac{1}{4}$	− 196	$105\frac{1}{4}$
„ 15	$301\frac{1}{4}$	+	$13\frac{3}{4}$	=	315	− 207	108
„ $15\frac{1}{2}$	315	+	$13\frac{3}{4}$	=	$328\frac{3}{4}$	− 219	$109\frac{3}{4}$

This somewhat full treatment of the steel wire, has been prompted partly because of the position it holds historically, as rendering possible the advance from the old type of piano, but more, because the string, considered in its length, diameter, tension, and point of agitation, is the most important factor in the production of tone.

The sound-board is also of great importance, as an expander of the vibration forms of the strings, but it gives out nothing which is not first supplied to it. Had this always been understood, and string proportions properly adjusted, much waste of ingenuity, which has been expended in experiments on sound-boards, made under the mistaken impression that they are tone-producers, might have been avoided.

It has been shown that the superiority of the modern piano is fundamentally a matter of string tension, and we now propose to discuss this point: first, in relation to the tenacity of the wire; and, second, in relation to the strain-resisting structure.

Why has the increase of tension resulted in such remarkable improvement? Even before any considerable advance was made, there was floating in the minds of piano makers a prophecy of the truth, in the oft-repeated dictum that "the nearer the tension approached the breaking strain of the strings the

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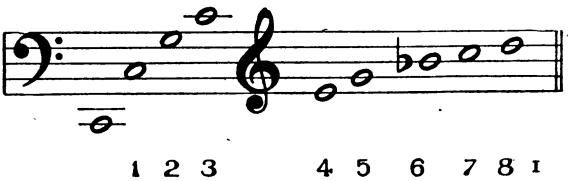
better the tone"; and in this idea may be traced a vague recognition of the fact that the higher the tension the greater the elasticity of the string, and the smaller (in relation to the force which sets it in vibration) the extent of its first transverse movements, and consequently the more distinct its divisions into shorter vibrating segments for the production of those overtones, which, when properly developed, add so much to the richness of piano tone in the tenor and bass portions of the compass.

The movements of a string, doing its best musically, are not at all easy to follow; indeed, to form a mental conception of them is difficult. They are very different from the mere back-and-forward, changing to side-to-side, swings, which is the ordinary supposition. That motion is, of course, present; indeed, it can only be prevented by highly artificial expedients, and it is very necessary, but not more so than the others.

For the production of first-class tone we need the string to vibrate in numerous modes, the first giving the fundamental sound (the one we recognize as the pitch of the note) and seven overtones or upper partials, the highest being the third octave above the fundamental. Others higher in pitch are possible but as among them some are dissonant with the fundamental (and others of the partials) their presence is far from desirable.

As a convincing instance, we may mention the 8th overtone. If the fundamental is C, the 8th overtone will be D, three octaves and one note higher, producing a clashing discord with the fundamental and others in the series, which series, however, is harmonic up to the 7th. The ascending order is as follows:



[1] See Appendix.

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These should all be present in varying degrees of intensity, except the 8th.

There is a way of silencing overtones which we shall mention later. The point we are now striving to make is, that the tension which develops the fullest elasticity of the string, is also that which favours its division into those smaller vibrating portions necessary to the production of the overtones.

Every textbook on "Sound" gives a diagram intended to illustrate the complex and superposed forms of the vibrations, but they have to be isolated and drawn on straight lines, and therefore these illustrations cannot convey a proper sense of the

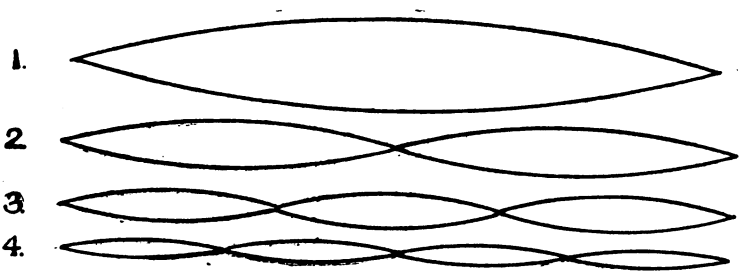

FIG. 4.

vibrational forms. Here, however, is what is intended to represent the lower four of the desirable modes, but they must be supposed to be all moving together, superposed on No. 1 and on each other.

We said earlier that when the subject of overtones should be reached, the effect of wire not being quite round would be discussed.

The tone defect called "falseness" (so distressing to the tuner) is evidently the result of discordance among the overtones, and cannot in most instances be due to the prominence of those naturally dissonant, like the 8th, because the trouble will often show itself in a single string, while its associates (in a trichord note) are pure. The suggestion is here made, that

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discordance may be due, in such cases, to the wire being slightly oval *and twisted*, so that the flexibility of the string is unequal, and it therefore cannot divide quite equally.

Other causes sometimes operate to produce a similar effect, for instance bridge pins not being sufficiently firm, and therefore able to make minute movements in response to the vibrations of the strings, instead of presenting a rigid obstacle; but many experiments have shown the first cause stated, to be a fruitful source of the trouble.

Our problem seems now fairly developed. We have before us the strength of the wire now available, and some cogent reasons why the tension should be as high as practicable. The question therefore is—

How high a Tension is desirable?

Evidently there must be a considerable margin allowed for safety, over the stretching force required to produce the note. There is the friction of the bearings to be allowed for, the force of the blow of the hammer (an as yet unascertained quantity) and also some loss in strength where the wire is distorted, as in coiling upon wrest-pins or passing around hitch-pins. Then we must take into account the ability of the structure to resist the total pull, and of the wrest-plank and wrest-pins to endure the strain.

The writer has scaled pianos on the basis of top C, 5·6 cm. long, strung with No. 13½ wire, resulting in a tension of 194 lbs. per string, 582 lbs. per note, and this left 40 per cent of the ultimate tensile strength of the wire used for the top note, to meet the other calls enumerated above.

So that even were a slightly longer string used, carrying a strain, say, of 200 lbs., we should hardly be in the danger zone if our wire were of good quality. But to render safe such a total strain as this would produce, viz., 23½ tons, would require an extra heavy iron frame, a full cast—in wrest-plank plate, and

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specially long and strong wrest-pins, and also the strings would need to be so aligned as not to exercise a forward pull upon the top part of the structure. Unless all these precautions can be taken, a tension higher than will result from top C, No. 88, 5·4 cm. in length, strung with wire of 13½ gauge, and which will come to pitch at about 173 lbs. per string, cannot be recommended.

Seven and one-quarter octaves compass is being increasingly used, and therefore this note is made the basis for calculation—the datum point from which all other string lengths are determined. Should only seven octaves be required, then C, B, and A♯ are just left out.

Having fixed the dimensions for this note, the next business is to calculate the lengths and gauges for the other C's as far as the height, or length (if a grand) of the instrument will permit the scaling to be regular.

In former days it was regarded as proper, in the upper half of the instrument, to double the lengths of the octaves descending, and the use of thicker wire was fixed just haphazard.

I have examined pianos even by makers of high repute, in which the strings were *more* than doubled in length, octave by octave.

Equality of Tension

It is now known from experience that practical equality of tension throughout the instrument tends to prevent changes in the tuning due to variations in the temperature. When the tension is equal the temperature movements are equal.

In former days pianofortes were exceedingly sensitive to changes of temperature, mainly because the fact noted above was unrecognized, or disregarded.

A thermometric movement of a few degrees often sufficed to render (in a very short time) an instrument unusable, and had the tuner recently paid one of his visits, the discredit of the change was charged to him.

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The notes in which the greatest changes occurred, were the lower ones which were strung with plain steel wire.

I have known numerous instances in which the changes in these notes were equal to nearly a semitone between midsummer and midwinter, while the other parts were comparatively stable.

This was due to the customary very low tension of these notes.

There seems to be a point in an ascending scale of tension, at which the elasticity of the wire is almost suddenly developed to an extent we could not anticipate, so that a difference, which would be very serious at a general low tension, will become more tolerable.

To make this intelligible, let us suppose an instrument in which the tension of pitch C is 130 lbs., and that of C two octaves lower is only 100 lbs. This piano will be exceedingly sensitive.

But let us now suppose that we can lift the tension so that pitch C stands at 200 and the other at 154 lbs. While there still remains a liability to change, it is much reduced, although the ratio of the difference is unaltered. Covered bass strings, which are usually at a rather high tension, seem immune from this disease.

Equal tension could be ensured by doubling string lengths octave by octave, and stringing throughout with one gauge of wire. One result of this would be that the speaking length of the lowest C would be about 22 ft. 6 in. long, and so upright pianos on this method would be quite impossible.

If, as is commonly supposed, it was this which led the minds of the early makers of pianos to a graduation of diameters of strings, to compensate for loss in length, then, as already said, the ratio of the graduation was most fortunate. Perhaps, however, the graduation of the gauges was the work of a man who saw a little deeper than his contemporaries.

A further result of doubling the lengths would be an unmanageable flexibility in the middle and lower

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notes, which would show itself, not only in weak and hollow tone, but, under even moderate blows of the hammers, the excursions which the strings would make from line, would be much larger than the spaces between them, and they would jangle together.

The ratio of flexibility to length is, that *tension and diameter being constant*, the flexibility varies directly as the length. If you double the length you double the flexibility. This of course assumes that the flexure is always measured at the same proportion of the length.

When the subject of the striking proportion is dealt with, it will be seen that to double the length of descending octaves really results in a flexibility of about as 2·25 : 1 instead of as 2 : 1.

The difficulty is overcome by thickening and shortening the strings in such a proportion, that the *mass* of each descending octave is doubled, but the flexibility is not unduly increased. The best results are secured when the notes in each octave are thicker (than in the octave above) by one whole gauge, and the lengths are measured as 17 : 9. Even this cannot be continued much below mid C, except in very tall upright pianos, or in grands longer than, say, 6 ft., and recourse has to be had to further shortening and thickening, and so the gauges, which in the above calculation are increased by half a number at each C and F♯ have to be crowded together.

But this also cannot be continued indefinitely—that subject of flexibility turns up again *in reversed order*: the notes get *too* stiff. At some part any further increase of length is barred: the lowest note on the long bridge ought not to be nearer at the lower end of the speaking length, than 5½ in. or 6 in. from the edge of the belly glueing. This position must result in a curve which will make several of the lower notes very disproportionately short, and the tensions correspondingly low, unless the wire with which they are strung is excessively thick, which will make the tone of such notes short and "barky."

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The alternative is to make those notes which would require larger wire than No. 21½ of spun strings *bichord*. These, however, if of the same tension, would be a little too flexible, due to two causes: first, each spun string is more flexible than each steel string it replaces and, second, there being only two instead of three of them, the resistance to the blow of the hammer is further reduced by one-third.

A very satisfactory way out of this difficulty is to make these strings of such components as will require a tension of about 15 per cent above the adjacent trichord strings. This does not make the flexibility quite equal, and of course causes a slight sacrifice of equality in the tension, but a break in the tone is averted, and there does not seem to be any disadvantage. I have used this expedient for many years.

The selection of these covered strings, the relative thickness of core and covering wire, can best be done experimentally on a tension machine.

There is now to consider the proportions of those covered strings which occupy the *bass* section of the instrument. In former times these were the only spun strings used, and as in vertical-strung uprights and straight-strung grands all the length possible was used upon the long bridge, the notes in the bass section of necessity started shorter.

The examination of many old instruments by renowned makers disclosed a fairly uniform practice, which, however, seems to have been merely customary, no scientific reason being discoverable. It was this—they made the first covered note shorter than the steel one next above, by about ⅞ in. in each foot.

In overstrung upright pianos there is no reason at all why the top note of the bass section should be shortened in this way. My own practice is to make this note as much longer than its next neighbour above, as it would be were it upon the same bridge, and use strings dimensioned to give the same tensions. This method avoids a break of tone at this place also.

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The thickness of the covered strings below this point often depends upon the number of pounds of copper the maker can afford to use.

It is not likely that in any ordinary upright piano the limit of tension will be greatly exceeded, nor will too great stiffness give trouble; but if the strings are very light, undue flexibility may result from low tension. Where the break occurs between bichord notes and those with single strings, a large tensional advance is advisable.

The words "elasticity" and "flexibility" have already been frequently used, and probably will be used many more times in this treatise. These words are commonly regarded as almost interchangeable, although the true meanings differ very widely. Flexibility is that quality in a material which renders it capable of being altered in shape. Elasticity, however, is that quality by which a material recovers its shape after distortion. Lead is one of the most flexible of the metals, but its elasticity is almost nil; while steel of medium temper is only moderately flexible, but immensely elastic.

The degree of these qualities, however, is affected by the conditions, so that a steel musical string at *very low* tension, may be very flexible and only moderately elastic; while the same string, at a much higher tension, will be much less flexible and much more elastic.

This note seemed necessary to guard against misunderstanding.

String Lengths and Diameters

What then shall be the lengths and diameters of strings to produce a succession of notes at a tension of 173 lbs. per string? To secure this result it is required that in each descending octave each note shall contain twice the *mass* of the corresponding note in the octave above.

To double the length of the strings and leave the

Not quite correct.

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diameter equal, is not admissible for reasons given. The lengths must be less than double, and the diameters increased in proportion. The length and diameter for top C is arranged as 5·4 cm. 13½ wire of area 0·502 mm. The next whole step in the wire gauge gives us 14½; area 0·568 mm.

Accepting this wire for the C next to the highest, what length has the note to be, to make its "*mass*" just double? To arrive at this we have to multiply the length of the top note by ·2240, the square root of the area of 13½, and divide the result by ·2382, the square root of the area of 14½, and double the result. Thus:

5·4 cm. × ·2240 = 1·210, ÷ ·2382 = 5·1 cm. × 2 = 10·2 cm., nearly.[1]

The length proportion of these notes stands now as 9 : 17, the mass proportions as 1 : 2, and the requirements as to flexibility are met. These proportions must be maintained in the octaves downward as far as possible, and work out thus:—

	13½	14½	15½	16½	17½	18½
C ...	5·4	10·2	19·25	36·4	68·8	131 cm.

The proof of the 9 : 17 proportion is thus:—

5·4 cm. × 17 = 918, ÷ 9 = 10·2 cm.

There is now to subtract the short length, 5·4 cm., from the longer one, 10·2 cm.; thus:—

10·2 cm. − 5·4 = 4·8 cm. remainder.

This remainder has to be divided into twelve portions corresponding to the twelve semitones in the octave. The division is, of course, not equal, but has to be adjusted to the vibration rates of the successive semitones.

Were our octave lengths as 1 : 2, the semitonal proportion would be as 33 : 35, which is the ratio of the vibration numbers. But having to modify our length proportion for octaves, compels also a

[1] Expressed in such figures as can be used in practical work.

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modification of the length proportion for semitones, which therefore has now to be: as 37 : 39, so is any semitonal length to that of the next below it. Thus:—

C 10·2 cm. × 37 = 3774, ÷ 39 = 9·7 cm. for C♯, nearly.

and this process has to be continued step by step until C 5·4 is reached, and then repeated for each lower octave.

Or it can be reversed and, beginning at C 5·4 cm. continued downward till the lowest note—which can be treated in the regular scaling—is arrived at.

It will doubtless be of value to have the full scale ready worked out, as under. Table No. II.

TABLE No. II.

STRING LENGTHS IN CM.

C	B	A♯	A	G♯	G	F♯	F	E	D♯	D	C♯
5·40	5·69	6·00	6·33	6·69	7·02	7·42	7·81	8·25	8·71	9·20	9·70
10·20	10·75	11·35	11·99	12·64	13·35	14·05	14·80	15·63	16·48	17·40	18·30
19·25	20·30	21·40	22·60	23·80	25·10	26·40	27·90	29·50	31·10	32·80	34·60
36·40	38·40	40·50	42·70	45·00	47·50	50·00	52·70	55·70	58·70	62·00	65·20
68·80	72·50	76·60	80·70	85·00	89·80	95·00	99·90	105·20	111·10	117·00	123·10
131·00	137·00	—	—	—	—	—	—	—	—	—	—

The proportions are all as 9 : 17 for octave lengths, and as 37 : 39 for semitones, giving equal tension at equal temperament.[1]

In Table III (p. 28) it will be shown that the above lengths, multiplied by the square roots of the sectional areas of the wires, result in mass, which, when again multiplied by the vibration numbers of the notes, gives a practical constant, proving the correctness of the measurements.

We will now consider a geometrical method of measuring the semitone lengths (Fig. 5).

Take a sheet of drawing paper, say, 60 in. by 30 in., and carefully dry the same. This precaution against shrinkage should always be taken. The paper should

[1] The proportions given are near simple ones. See Appendix.

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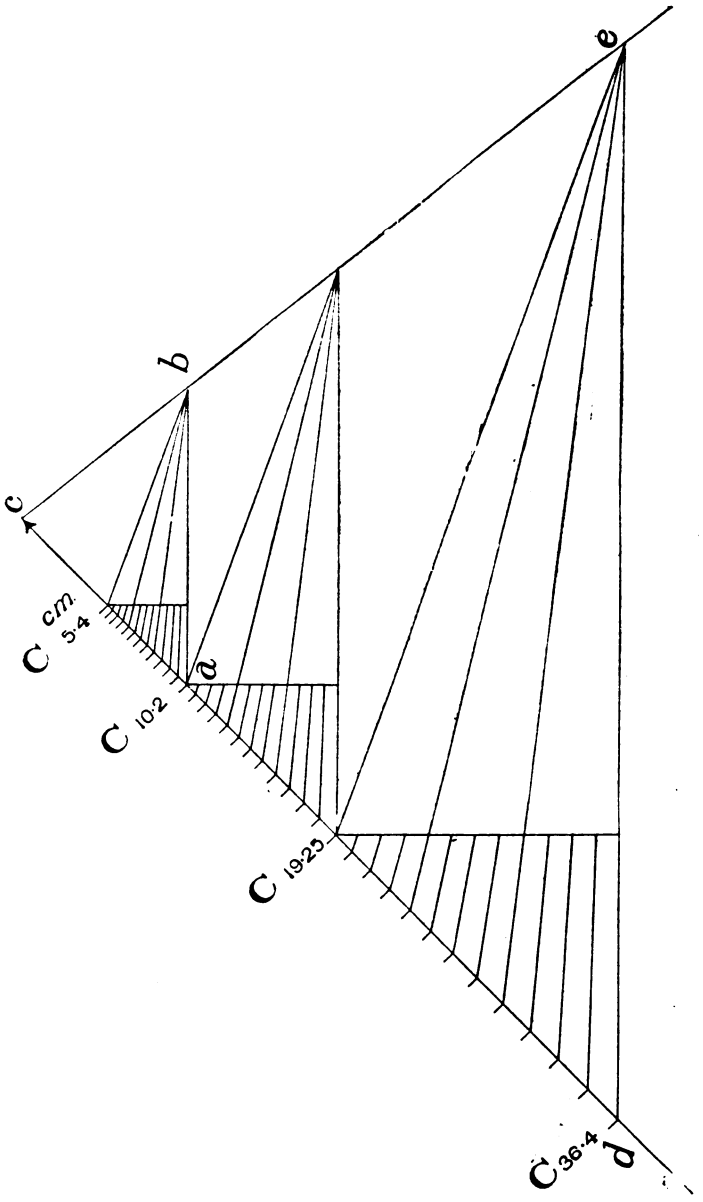

FIG. 5.

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be of good quality, as cheap papers quickly deteriorate. At about 9 in. from the top edge draw a base-line *ab*. This may be of indefinite length. From this, at *a*, draw a line making an angle of 45 deg. with *ab*, and produce this line upward and downward to the edges of the paper (line *cd*). On this line, from *a*, measure upward very accurately 10·2 cm., and define the point *c*. From this point, downward, measure 5·4 cm. (10·2 is already fixed), 19·25, 36·40, and 68·80, and from each of these measure-points rule lines *exactly parallel* with *ab*. Now, from *c* draw another line *ce*, making an angle of 51·5 deg. with the parallels, and where this line cuts each parallel make a fine needle-prick. The length of each parallel is to the length to be divided for semitones, as 35 : 13. From each of the measured points on *cd*, drop a perpendicular reaching to the next parallel, and rectangular to it. Divide each perpendicular into twelve equal parts. This must be done with extreme care. Now rule fine lines from the needle-marks made in *ce* through the divisions in the perpendiculars, and reaching to *cd*. If this work is very carefully done the lengths are defined, measuring from *c* upon *cd*, for all the notes in the four principal octaves, graded as per the "New Westphalia Gauge," for equal tension.

The above is a very practical method of determining string lengths, and in past years I used it altogether, but now find the arithmetical way somewhat easier.

In all the calculations, the use of the "French Normal" pitch, 517·3 vs. is assumed. Should either of the higher pitches be used, the effect of the following law will be felt: "If the length and diameter of a musical string are constant the stretching force varies as the square of the frequency, i.e. vibration rate per sec. So that if pitch C 517·3 vs. is produced by a stretching force of 173 lbs., 522 vs. will require 176; 530 vs., 181; and 540 vs., 189 lbs. respectively.

The gross additions to the strain on the structure

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TABLE No. III.

1 Note and Number.	2 Length. (cm.)	3 Number of Wire.	4 Diameter of Wire. (mm.)	5 Square Root of Area of Section of Wire.	6 Mass (Length × Square Root of Area).	7 Frequency.	8 Constant (Mass × Frequency).	9 Tension in lbs.	10 Probable Actual Breaking Strain in lbs.	11 Margin in lbs.
C 88	5·40	13½	0·800	·2240	1·210	4138·440	502	173	275	102
B 87	5·69	14	0·825	·2310	1·314	3906·168	512	180	291	111
A♯ 86	6·00	14	0·825	·2310	1·389	3686·932	511	179	291	112
A 85	6·33	14	0·825	·2310	1·461	3480·000	509	177·5	291	113·5
G♯ 84	6·69	14	0·825	·2310	1·545	3284·684	506	176	291	115
G 83	7·02	14	0·825	·2310	1·621	3110·328	505	175	291	116
F♯ 82	7·42	14	0·825	·2310	1·715	2926·320	502	173	291	118
F 81	7·81	14½	0·850	·2382	1·860	2762·076	513	180·5	306	125·5
E 80	8·25	14½	0·850	·2382	1·970	2607·052	512	180	306	126
D♯ 79	8·71	14½	0·850	·2382	2·081	2460·732	512	180	306	126
D 78	9·20	14½	0·850	·2382	2·190	2322·620	507	176·5	306	129·5
C♯ 77	9·70	14½	0·850	·2382	2·310	2192·264	505	175	306	131
C 76	10·20	14½	0·850	·2382	2·430	2069·220	502	173	306	133
B 75	10·75	15	0·875	·2455	2·640	1953·084	514	181	321	140
A♯ 74	11·35	15	0·875	·2455	2·780	1843·466	512	180	321	141
A 73	11·99	15	0·875	·2455	2·940	1740·000	511	179	321	142
G♯ 72	12·64	15	0·875	·2455	3·120	1642·342	511	179	321	142
G 71	13·35	15	0·875	·2455	3·267	1550·164	507	176·5	321	144·5
F♯ 70	14·05	15	0·875	·2455	3·441	1463·160	503	173·5	321	147·5
F 69	14·80	15½	0·900	·2520	3·720	1381·038	513	180·5	332	151·5
E 68	15·63	15½	0·900	·2520	3·940	1303·526	512	180	332	152
D♯ 67	16·48	15½	0·900	·2520	4·150	1230·366	510	178·5	332	153·5
D 66	17·40	15½	0·900	·2520	4·370	1161·310	508	177	332	155
C♯ 65	18·30	15½	0·900	·2520	4·610	1096·132	504	174	332	158
C 64	19·25	15½	0·900	·2520	4·840	1034·610	502	173	332	159
B 63	20·30	16	0·925	·2590	5·270	976·542	514	181	348	167
A♯ 62	21·40	16	0·925	·2590	5·540	921·733	511	179	348	169
A 61	22·60	16	0·925	·2590	5·860	870·000	510	178·5	348	169·5

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G♯	60	23·80	16	0·925	·2590	6·150	821·171	505	175	348	173
G	59	25·10	16	0·925	·2590	6·500	775·082	504	174	348	174
F♯	58	26·40	16	0·925	·2590	6·840	731·580	501	172	348	176
F	57	27·90	16½	0·950	·2656	7·400	690·519	510	178·5	366	187·5
E	56	29·50	16½	0·950	·2656	7·820	651·763	508	177	366	189
D♯	55	31·10	16½	0·950	·2656	8·230	615·183	506	176	366	190
D	54	32·80	16½	0·950	·2656	8·700	580·655	504	174	366	192
C♯	53	34·60	16½	0·950	·2656	9·200	548·066	503	173·5	366	192·5
C	52	36·40	16½	0·950	·2656	9·680	517·305	502	173	366	193
B	51	38·40	17	0·975	·2730	10·490	488·271	512	180	374	194
A♯	50	40·50	17	0·975	·2730	11·070	460·886	509	177·5	374	196·5
A	49	42·70	17	0·975	·2730	11·650	435·000	506	176	374	198
G♯	48	45·00	17	0·975	·2730	12·280	410·585	503	173·5	374	200·5
G	47	47·50	17	0·975	·2730	12·980	387·541	501	172	374	202
F♯	46	50·00	17	0·975	·2730	13·650	365·790	501	172	374	202
F	45	52·70	17½	1·000	·2801	14·750	345·259	509	177·5	384	206·5
E	44	55·70	17½	1·000	·2801	15·620	325·881	509	177·5	384	206·5
D♯	43	58·70	17½	1·000	·2801	16·490	307·592	505	175	384	209
D	42	62·00	17½	1·000	·2801	17·390	290·327	504	174	384	210
C♯	41	65·20	17½	1·000	·2801	18·310	274·033	502	173	384	211
C	40	68·80	17½	1·000	·2801	19·360	258·652	502	173	384	211
B	39	72·50	18	1·025	·2875	20·810	244.135	507	176·5	401	224·5
A♯	38	76·60	18	1·025	·2875	22·000	230·433	505	175	401	226
A	37	80·70	18	1·025	·2875	23·200	217·500	502	173	401	228
G♯	36	85·00	18	1·025	·2875	24·400	205·292	502	173	401	228
G	35	89·80	18	1·025	·2875	25·800	193·770	502	173	401	228
F♯	34	95·00	18	1·025	·2875	27·400	182·895	501	172	401	229
F	33	99·90	18½	1·050	·2943	29·420	172·629	506	176	410	234
E	32	105·20	18½	1·050	·2943	31·100	162·960	503	173·5	410	236·5
D♯	31	111·10	18½	1·050	·2943	32·700	153·796	503	173·5	410	236·5
D	30	117·00	18½	1·050	·2943	34·400	145·163	500	171·5	410	238·5
C♯	29	123·10	18½	1·050	·2943	36·400	137·016	500	171·5	410	238·5
C	28	131·00	18½	1·050	·2943	38·800	129·326	502	173	410	237
B	27	137·00	19	1·075	·3020	41·400	122·067	505	175	425	250

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would be 522 vs., 792 lbs.; 530, 2,112 lbs.; and 540, 4,224 lbs.; the last nearly equal to 1·9 tons.

Table No. III shows, column 2, the length of each note, from C, No. 88, down to B, No. 27, which is the lowest note usually placed upon the long bridge, and in column 3, the English music wire gauge number, of that which is to be used to secure equality of tension. The diameter of the wire in mm. is shown in column 4. No. 5, gives the square root of the sectional areas of the respective gauges, and is used to ascertain the "mass," which is length multiplied by square root of area. The same proportionate result could be obtained by multiplying length by diameter. Column 6, "Mass," is the result of this multiplication. Column 7, "Frequency" (vibration rate per second), is the work of a celebrated French acoustician, Dr. Koenig. The "Constant," column 8, results from multiplying the figures in column 7, by those in column 6.

It will be seen that while the approach to a constant is fairly close, it is not perfect. For this there are two reasons. First, as will be obvious, we can only use two half gauges of wire in each octave, instead of twelve gradations, and as the lengths are on fixed ratios there must be a rise in the constant, and in the tension, extending from each C to F, and from each F sharp to B upwards. Then the calculations, being slide-rule readings, are subject to the defects of such, the smaller fractions having to be estimated.[1] The next column, 9, "Tension," varies with the constant.

The constant given is really a square root and on the slide rule is used thus: Set an ascertained tension on scale B over the constant on D, and the variations of tension follow those of the constant. In a previous Table (No. I), we have given the theoretical breaking strain for each half gauge, with a note showing why it is unreliable.

Column 10 is an estimate of the probable *actual*

[1] This applies to all the calculations in the book.

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tenacities. This has been calculated on the basis of information supplied a good many years since by one of the most renowned wire-drawing firms. At that date they only claimed 250 lbs. breaking strain for No. 13; since that time great increase has been made in tenacity, and the column has been adjusted on the basis of 260 lbs. for No. 13, which is not extravagant. Even should the coarser gauges not have been correspondingly improved, the last column, No. 11, serves to show how unimportant it is, in view of the immense margin of safety.

The regular scaling has been carried right down, but except in fairly long "grands" it cannot be used.

The length for B, No. 27, is 4 ft. 6 in., and would require an upright overstrung piano, 5 ft. 7 in. in height, to accommodate it. About 4 ft. 4 in. is the largest being made in this country at the present time. So Table No. IV is drawn up to show how an adjustment may be made to the demands of average dimensions. These are—practical equality of tension must be maintained, and for reasons previously given, no wire should be used of larger diameter than No. 21½. An arbitrary shortening must therefore be made, which in this case should commence just below middle C, No. 40, and proceed in an increasing ratio to the bottom.

No rule can be made for this shortening, it depends altogether upon the dimensions of the instrument; but when later we are making practical application of the principles now being laid down, we will show how the difficulty should be met. This Table No. IV follows the method of No. III, and the wire numbers have been so adjusted to the lengths as to secure equality of "mass," and consequently of "tension." But it will be seen that E, No. 32, is the lowest note which can be properly strung with plain steel wire, and that to continue to the bottom would require the use of even No. 25.

Covered strings must therefore be selected, of appropriate diameter and tension. This, as previously

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TABLE No. IV.

1 Note and Number.	2 Length. (cm.)	3 Number of Wire.	4 Diameter of Wire. (mm.)	5 Square Root of Area of Section of Wire.	6 Mass (Length × Square Root of Area).	7 Frequency.	8 Constant (Mass × Frequency).	9 Tension in lbs.	10 Probable Actual Breaking Strain in lbs.	11 Margin in lbs.
C 40	68·8	17½	1·000	·2801	19·36	258·652	502	173	384	211
B 39	72·4	18	1·025	·2875	20·79	244·135	507	176·5	401	224·5
A♯ 38	75·8	18	1·025	·2875	21·75	230·433	501	172	401	229
A 37	79·1	18½	1·050	·2943	23·39	217·500	506	176	410	234
G♯ 36	81·9	18½	1·050	·2943	24·20	205·292	495	168	410	242
G 35	84·7	19	1·075	·3020	25·60	193·770	495	168	425	257
F♯ 34	87·3	20	1·125	·3150	27·50	182·895	501	172	457	285
F 33	89·7	21	1·175	·3290	29·50	172·629	506	176	489	313
E 32	91·8	21½	1·200	·3360	30·85	162·960	500	171·5	505	333·5
D♯ 31	93·9	22	1·225	·3440	32·30	153·796	495	168	532	364
D 30	95·9	23	1·300	·3650	35·10	145·163	509	177·5	575	397
C♯ 29	97·7	23	1·300	·3650	35·65	137·016	490	164·5	575	410·5
C 28	99·4	24	1·400	·3921	38·90	129·326	502	173	617	444
B 27	100·3	25	1·500	·4210	42·20	122·067	515	182	660	478

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stated, can be done very easily on a tension machine. However, an approximate rule can be supplied. Very fine spun strings do not much more than equal for tension plain steel ones of the same diameter.

This is not difficult to account for. The difference between the specific gravity of steel, and that of copper, should increase the tension of a *solid* copper string by about 14 per cent.

A recent analysis of a thin spun string, showed that out of a weight of 50 grains, 26 were steel and 24 copper, so the difference in the gravity of such a string over a steel one of the same diameter would only be about 6½ per cent. Were the copper casing solid, like a tube, the difference would be greater, but the interstices take off a considerable amount.

Were we needing, therefore, in these small diameters, spun strings to replace steel ones *at the same tension*, a fairly safe rule would be, just use the same gauge, but on account of the undue flexibility, resulting from the great reduction in the core wire requiring increased tension to compensate, the best way is to make the strings equal to one whole gauge larger. This conforms to the results of many experiments. Of course it is understood that the above reasoning applies only to *very fine* covered strings.

Table No. IV must not be regarded as an actual proposition; as said before, it is only an illustration of a method of working, and would have to be adjusted to the height of the instrument intended.

Should any one wish to use the grading of these Tables, who fears whether such iron frames as he can afford to use will bear the tension, he can easily make a transposition, thus: put another length in the treble, for C, No. 88, 5·12 cm. long, and strike out the lowest note, making C, No. 28, into B, No. 27. This will lower the whole scale one semitone, and reduce the tension by about 19 lbs. per string. Or wire can be used *one half gauge* smaller; this will reduce the tension by about 11 lbs. per string.

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CHAPTER III

SCALE DRAWING

EQUIPMENT

IT is presumed that any one essaying to make an accurate scale drawing, possesses a set of drawing instruments of good quality, with needle-points. This is of some importance; coarse impressions must not be made at places where later, sound spots may be required.

Pencils.—It is a mistake to use common ones, and not economical to have them in cedar, which requires to be cut to sharpen, and soils the fingers.

The pencil work is mostly ruling, the lines are long, and the pencils wear away quickly, requiring constant resharpening. For this reason they should be hard and durable.

A really efficient form is the "Artist's pencil," which consists of a hexagon cedar shaft, with screw grip to hold loose leads. These are stocked by most Artists' Colourmen, and are not expensive. The boxes of refills, each containing six, 5 in. in length, are numbered from 1 to 6; Nos. 3 and 5 are very useful, both rather hard and durable, No. 5 particularly so.

If it be desired to have only one sort let it be No. 3.

To sharpen (which should be frequently done), rub on glass-paper, *not over the drawing*, which will be sufficiently dirty before it is finished.

It is convenient to have a few needles, each gripped

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in a small watchmaker's "pin-vice" or "broach-holder"; these can be purchased at most of the tool shops, specially those which cater for watchmakers; the smallest size, about 3½ in. long, in fluted wooden handle is most suitable. These will be found invaluable.

Rulers, or Straightedges.—Use three: one 5 ft. long, one 3 ft., and one 12 in. They should be stiff; when a line 4 ft. to 5 ft. in length has to be ruled, a weak ruler may spring. Each ruler should have one edge slightly chamfered, to prevent blotting when "inking in" the finished work.

Squares.—It is advisable to have three set squares, thus: 2 ft., 1 ft., 6 in. If these are just made out of thin hard wood, they will be good enough, but both squares and rulers should be frequently examined and corrected if necessary.

Weights.—These are required for holding down rulers and squares, and also to retain in position spring laths (splines) when ruling curves.

They should be fairly heavy, and several will be found useful.

Those in constant use on rulers, &c., should be covered with cloth or leather, so as not to mark the paper when laid down; those only required very seldom, as when ruling curves, may be any rather heavy objects.

Protractor.—Only very occasionally wanted when a stated angle has to be found, and therefore an expensive one is not required.

These can be had in thin brass, fairly accurate, for a few pence, or larger ones marked on celluloid; even the very small ones (carefully used) will enable one to identify a quoted angle.

Metre Rule.—1,000 mm.

No one who has used the metric rule for scaling purposes will ever consent to be troubled again with the English scale for fine work.

It is very easy to use, and lends itself wonderfully to the needs of the calculator; the day will come when

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this or some other decimally marked rule will be in universal use.

The one selected should be full metre length (not folding), and if it can be had with the English scale on the other edge of the same face, it will be often found convenient. Also it should have upon the other side a 2 per cent contraction rule.

Such "metre sticks" are in regular use on the Continent, and can doubtless be procured at the foreign tool shops in London.

Steel ones are made by high-class English rule-makers, but are expensive, whereas the foreign ones are very cheap.

Proportional Compasses.—Those usually sold are far too small. Two special home-made pairs are required, and are constructed as shown in Fig. 6A and E.

Procure for the legs of one pair, two pieces of steel, say, 2 ft. 4 in. × $\frac{3}{8}$ in. × $\frac{1}{16}$ in., and for the stretcher one piece same section 3 ft. 2 in. in length.

Measure from one end of each of the 2 ft. 4 in. lengths $3\frac{1}{2}$ in.; carefully centre, and drill for a rivet (an ordinary piano desk rivet will do admirably); see that there is no side play in these holes. Rivet the two pieces together, and file the ends to points as shown, and see that when the long end is opened to 28 in. the short end opens to precisely 4 in. from point to point.

Should the proportion not come quite right at the first trial, correct with the file until it is exact.

Drill a hole about $\frac{1}{2}$ in. from one end of the 3 ft. 2 in. length and a corresponding hole about 4 in. from the point of one of the long legs, and rivet these together. On the other leg fix a spring grip, made of the same section steel $2\frac{1}{2}$ in. to 3 in. long, thus: drill two small rivet holes, one near the end, the other about $1\frac{1}{4}$ in. away from it, and corresponding holes in the leg.

Rivet this to the leg, with a short piece between as shown (Fig. 6*b*); just bend down the point of the grip a trace, and you have a first-class pair of large por-

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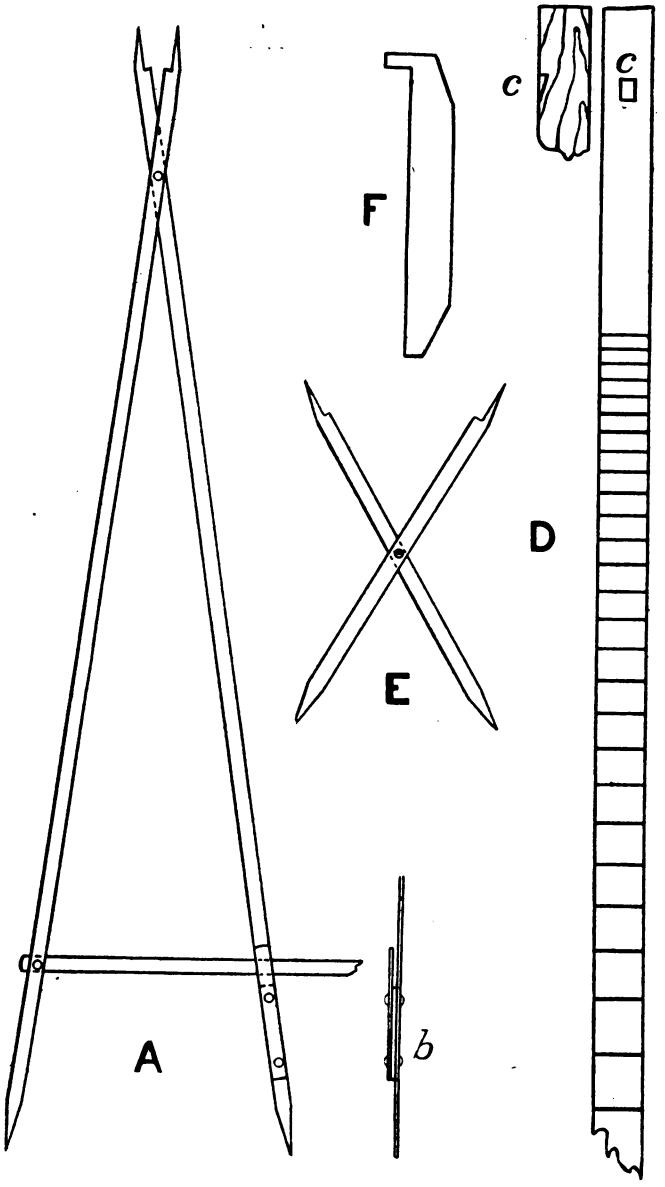

FIG. 6.

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portionals as 7 : 1 quite rigid when the stretcher is in the grip.

The special use of this will be seen later.

Another pair is required 10 in. long, but so centred that when one end is open 14 cm. the other shows 14·3 cm. the difference being only 2 per cent (Fig. 6E).

The steel for this pair can be of the same section as for the other, or if desired it may be $\frac{1}{16}$ in. narrower.

It is essential that the points be made as shown, as, being in proportions so nearly equal, there would be risk of mistaking the ends, were there not an obvious distinction.

No stretcher is needed, but the rivet should be very stiff.

The materials only cost a few pence and are easily obtained. Many firms in Clerkenwell and Soho stock various dimensions of steel in about 6 ft. lengths.

Micrometer Gauge.—For the actual work of scale drawing this is not a necessity, but for the study of scales it is. No aspirant to efficiency can afford to be without a critical gauge of this kind. They are now less costly than aforetime, and are graded to either 1,000ths of an inch or to 100ths of a millimetre; the latter is far the better for the scaler.

Drawing-board.—This should be as flat as possible, and fairly stiff, made of very mild wood—pine is best—not clamped at the ends, but with screwed battens underneath. The edges and ends should be shot straight and rectangular to each other; it is convenient to use a square from the edge of the board sometimes.

The dimensions should be according to the work; if for upright pianos only, 5 ft. × 4 ft. 6 in. will be large enough, but for grands at least 6 ft. × 5 ft.

The Scale Rod.—One should be made for every style of piano which is designed, and preserved for reference.

A piece of light-coloured hard wood, straight in the grain, should be selected; maple is excellent.

It should be about 5 ft. long × $\frac{7}{8}$ in. × $\frac{7}{8}$ in. care-

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fully planed straight and square, and the four faces glass-papered. One face should carry the string length scale, another the strike line scale, and the other two, the long bridge bottom scale, and the bass bridge bottom scale respectively.

The three latter being related, should tally with a common datum squared round three sides of the rod. The most convenient place for this datum coincides with the mark on strike line scale for middle D, No. 42 (see Fig. 7).

The string length scale being independent, can be marked first, but usually the others must wait until some of the main lines are on the drawing.

We will suppose that a geometrical scaling sheet as Fig. 5 has been made. The rod must now have squared upon it a mark to tally with *c*; this may be about 4 in. from one end.

Now let it be laid on the scale sheet on the line *cd*, the mark just mentioned coincident with *c*.

Let all the string lengths be carefully pricked off with a needle, and afterward squared off.

When squaring, the eye will detect whether there is any irregularity in the grading, and care must be used to correct same; this is important in the two upper octaves.

Or, the marks may be squared off direct from the sheet with a small set square, but the first method is the better one. If the marking be carried below middle C, let the squaring of these notes be done lightly, with a pencil, so that those not wanted, can be easily erased.

When the length of the lowest note on the long bridge can be determined, those intermediate between that and middle C, can be put in, as also the first and last on the bass bridge.

Or let us suppose that the rod is to be marked off from an arithmetical table as No. III.

In that case fix the metre rule and the scale rod together, with the beginning of the rule to *c*, and its face a hair below the rod, then by reading from the

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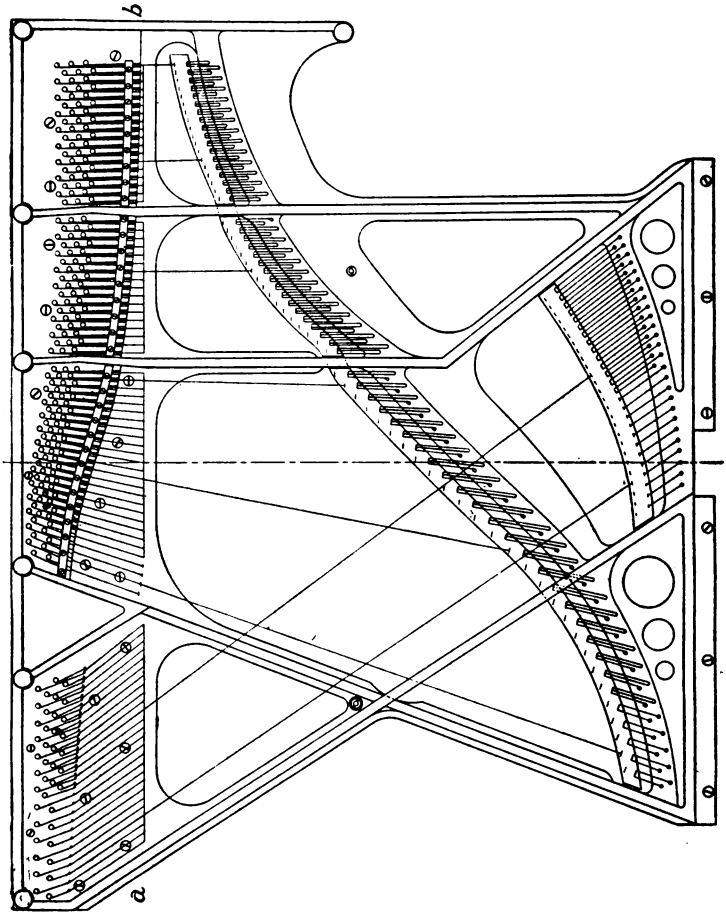

FIG. 7.

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table to the rule, the positions can be squared off direct.

When doing this, it will be realized how absurd (for practical work) are decimals of mm. except indeed 0·5 mm. When marked off, the treble end of the rod will present the aspect of Fig. 6D. Make a small notch in the centre of the width, at *c*, with a ¼ in. chisel, as shown in the side section.

The Strike Line Scale should be carefully considered.

There are few things more wasteful in a piano factory than a variety of strike scales.

The writer has known cases where most extravagant stocks of keys and actions, have had to be carried, because of failure to standardize.

There should only be two for upright pianos, and this supposes that both vertical and overstrung instruments are being made.

We shall assume that the instrument to be now scaled is an upright overstrung, and that it is the first of this type, or if not the first, is to become the standard.

The first question to be answered is, how many intermediate bars shall there be in the iron frame?

There was a time when English pianoforte makers had a deep-rooted objection to divisions and inequalities in the strike scale.

There is really no ground for objection; it arose from many years' usage of the old equal scale.

Overstrung uprights are very frequently made with two breaks, but the plan of placing two bars intermediate between the crossing break and the treble bar is growing in favour for high-class pianos.

The writer does not know of any (even economical) advantage in there being only two breaks, and therefore assumes that there will be three.

There are some variations in the placing of the bars, and there does not seem to be any special reason to justify any one of them.

This, however, may be said—the more nearly the

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two breaks above the crossing divide the remainder into equal portions the better.

An absolutely equal division can, however, only be made at the risk of placing the bass section upon a disadvantageous position on the sound-board, the division depending upon the angles of the crossing of the bass and tenor strings.

Perhaps as good an arrangement as is possible is—

Bass Section	26 notes	1 to 26
Middle Section	27 „	27 „ 53
Lower Treble Section	17 „	54 „ 70
Upper Treble Section	18 „	71 „ 88

The centre line of note No. 1 to make an angle of 60 deg. with the horizontal strike line, that of No. 26, 50 deg. ditto, and that of No. 27 a reverse angle of 70 deg.

By sacrificing in part the advantage which this arrangement gives to the bass notes, in length of strings and position on the sound-board, fewer notes may be included in the middle section, and more in the two treble ones, the angles given for the bass section being altered accordingly.

No real tone advantage results from an extra long strike scale and wide division of the notes. The writer has made strike line scales so long that it has been necessary to strengthen the keys with hard wood underneath on account of the excessive splays toward each end.

This presents a real difficulty, and there is also another disadvantage, viz. that the wider the divergence between the front and back scales of the keys the further the balance pins are out of the direct line from front to back.

These difficulties are of course more pronounced in short than in long keys.

As now made, the front key scale usually measures about 120·7 cm. from centre to centre of the part behind the heads A to C 88 notes.

If then the back scale should measure 125·8 cm.

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there will be 5·1 cm. to be divided between the two ends.

A convenient arrangement is as follows :—

From centre of A, No. 1, to centre of A♯, No. 26, 35·2 cm.
Break of 4·5 cm.
From centre of B, No. 27, to centre of C♯, No. 53, 36·1 cm.
Break of 3·2 cm.
From centre of D, No. 54, to centre of F♯, No. 70, 21·2 cm.
Break of 3·2 cm.
From centre of G, No. 71, to centre of C, No. 88, 22·4 cm.

Making a total length of 125·8 cm.

Even should it be decided to use an existing strike line scale, differing from the above, it is still wise to subject the same to critical examination; deterioration in accuracy is easy, and the curves, which are to result from properly measured string lengths, demand regularity of spacing.

Assuming that the scale above proposed is adopted, let the lengths be squared off on the rod.

The two upper sections are to be equally divided; the widths are about 13·25 mm.

There is nothing more discouraging than the attempt to set out a scale to fill a certain length by successive measurements.

There is an easy geometrical way, which can also be made available for increasing scales.

On a sheet of paper, say about 4 feet in length and of sufficient width, draw a straight line near one edge, and close to each end erect a perpendicular quite rectangular to the base line.

Divide the lower part of the right-hand perpendicular into 30 half-inches, and the left-hand one into the same number opened to, say, 1⅛ in.

The point to be aimed at in these divisions is, that at the one end they shall be a little closer than is

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ever likely to be needed, and that at the other they shall be somewhat wider than the widest requirement.

Let uniting lines be drawn between the points marked on the perpendiculars (Fig. 8).

It is obvious that at any place between the perpendiculars an equal scale can be found.

So having already marked on the rod the ends of the sections to be divided, find that place on the sheet at which the right number of lines coincides with the marks for the ends of the two treble sections.

It is hardly needful to say that for *equal* spacing the position must be rectangular to the base line.

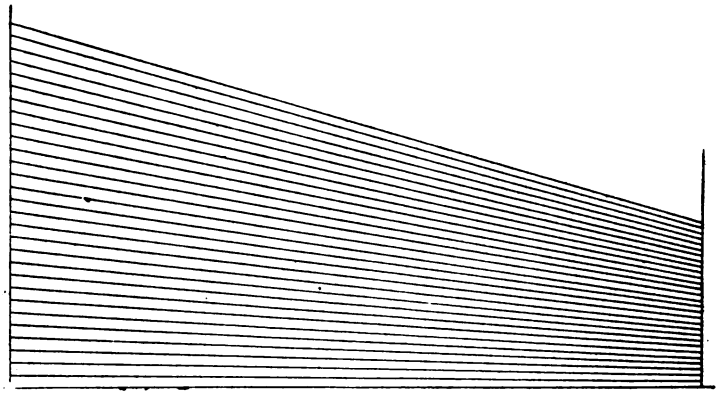

FIG. 8.

The middle section is *not* to be equally divided, but the spaces are to increase in width toward the bass end.

The reason for this is the increasing slant of the strings, which causes more room to be required for the hammers, and also for the wrest-pin scale.

For this the fan is invaluable.

Mark on the rod the width which is to separate No. 27 from 28, and No. 52 from 53.

Let the former be 15 mm. and the latter 13·25 mm.

An oblique line must be found upon the fan on which the right number of divisions coincides with both pairs of marks, and in this position the intermediates must be pricked off upon the rod.

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The centres of the 27 notes are thus graded regularly, increasing from 13·25 mm. to 15 mm.

The bass section should be only very slightly graded; the average for the whole is just over 14 mm. per note.

Set Nos. 1 to 2 at a little under 15 mm., and Nos. 25 to 26 just 14 mm., and find a position on the fan scale as before; the line will be only slightly inclined.

There is no increase of slant in the lower part of this section; indeed it is rather the other way, but for several reasons it is convenient to have the spaces increase a little.

The two treble sections of the bottom scale being identical with the strike scale may now be squared off from it, and at the same time the datum mark, that of middle D, No. 42, may be squared upon both the vacant faces of the rod.

The paper for the scale drawing should be of best quality "thick cartridge," 60 in. wide, and as long as required for the height of the piano.

The face of the paper should be smooth, not "sand grain."

It is preferable for this main drawing, to have the paper mounted on holland or calico; it is subject to a good deal of handling, having to serve as a master template, from which working ones are pricked off.

The cost of the mounted paper is not great, and the paper itself need not be so heavy as it requires to be if not mounted, but in any case it must be good; it is most annoying (if for any reason some part must be erased after inking) to scrape through a fairly hard surface to mere pulp, on which a new ink line "runs" almost as it would do on blotting paper.

The caution previously given as to shrinking the paper must be observed, particularly if it has been recently mounted.

It must not be supposed that a large drawing can be made on plain paper and mounted afterwards; the shrinkage in that case is tremendous.

It is wise in any circumstances to write upon a

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drawing its outside dimensions, so that at any time its shrinkage or expansion may be ascertained and corrected.

The Inks.—For the method of working which will be advised, four colours are required, so as to allow four layers of drawing to be superposed and yet not confused—Green, Red, Blue, and Black—the latter, one of the prepared Indian inks, the others may (if desired) be ordinary writing inks.

The drawing can now proceed as follows:—

Mark a line for the strike position, *ab*, Fig. 7: this can be 10 in. down from the top edge of the paper.

On this line prick off with a needle, the strike scale observing that the mark for the lowest note is not less than 5 in. from the edge of the paper.

From the mark for D, No. 42, square down a line, and produce it to the top and bottom of the sheet.

It is wise to be careful about this line. Put the straightedge to the strike line and apply the largest square both ways; this is to be a datum.

The angles for the centres of notes Nos. 1, 26, and 27 must now be set.

There is no great advantage in overstringing if the crossing angles are small.

The main advantages to be secured are—length of strings, and a more suitable position on the sound-board for the bass bridge than is possible in vertical stringing.

But considerable angles at the crossing cause difficulties.

It is not supposed that any one thinks of using overdampers in such an instrument as we are now considering, the reasons belong to another section of our subject.

There must be room on notes 27, 28, and 29 for the action of underdampers without fouling the hammers.

To settle this matter, place on each side of the line

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which stands for note 26, another line representing the width of a bichord note.

Then take the radius of the front of the hammer which will be used for the note, and from the intersection of the strike and centre line of No. 27 make an arc downwards.

Where this arc cuts the centre of the note, will be the highest point which can be occupied by the damper without striking against the hammer, and the length of the damper is plainly insufficient.

The crossing angles can only be reduced at some sacrifice of advantages, and to increase the width of the break on the strike line is undesirable.

The practical and usual way out of this difficulty is to raise the strike position of three or four notes.

Measure on the centre line of No. 27 a point 10 mm. above the strike line, and with a compass set to a radius of about 7 in. make an arc joining this point and the strike line at No. 30.

This will provide room for a damper of about $1\frac{5}{16}$ in. long.

This expedient has the effect of carrying the actual strike position for the hammer a sensible amount to the treble side, and this must be in part avoided.

Therefore for the three notes affected, square up the centres from the strike line, and when ruling in the string lines compromise to the extent of one-half the difference.

This course has the advantage of further widening the openings between the hammers of these notes in case the use of fly dampers should prove desirable, as sometimes does occur.

Of course these new positions become the measure points for the strike proportion of the strings, and when the bridge curve is finally ruled, a further small compromise may be required.

The effect of the increase in the length of the hammer shank is only about 8 per cent on the speed of the hammer, which does not affect the touch appreciably.

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The bottom scales on both the rod and the drawing can now be marked.

For the two treble sections this is identical with the strike line scale, and is already squared off from it on the rod.

Let the mark for No. 53 be treated in the same way, and let lines to represent the centres of Nos. 53, 54, 70, 71, and 88 be ruled right down the drawing parallel to the centre datum line (Fig. 9).

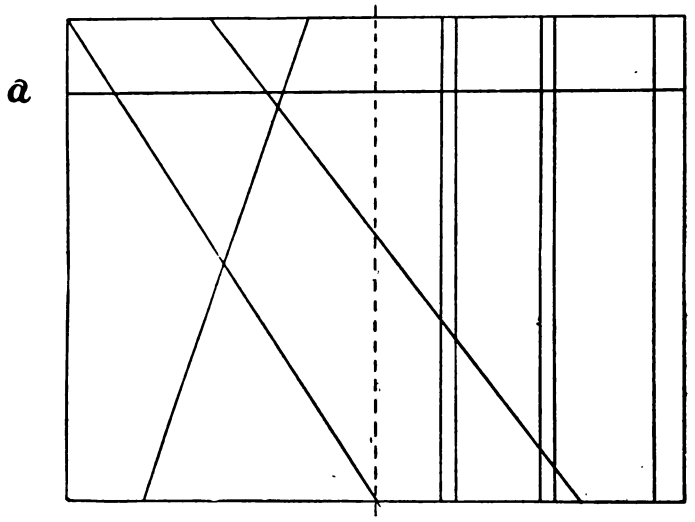

FIG. 9.

The bottom of the back and iron frame must now be defined, and to position this the height of the whole must be determined.

Say it is to be 4 ft. For this height there is required approximately 8½ in. between the strike line and the top, leaving 3 ft. 3½ in. below.

These dimensions vary with the length of the longest strings in the middle section; thus, for every increase in the length of these, add one-eighth above and seven-eighths below the strike line.

On the bottom line the bottom scale is to be marked, except for the bass section. The centres therefore from 53 to 88 are pricked on the drawing from the

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rod and that for No. 27 on the rod from the drawing.

The space from 27 to 53 has to be equally divided, for which use the left-hand side of the sheet (Fig. 8).

Having marked the rod, transfer to drawing.

There remains to make the bottom scale for the bass section.

The centre lines for Nos. 1 and 26 are already fixed.

It is usual for the distance between these lines to be wider at the bottom than at the strike line, but not so much so as to bring the lower end of the bass bridge upon a stiff inactive part of the sound-board, the angles advised secure a maximum of advantages.

Rule the line for the bass bottom scale ¼ in. below the bottom line. The reason for this is that there is already one scale upon that line.

Upon the remaining unused face of the scale rod, with the datum in contact with the centre line upon the drawing, square off marks for Nos. 1 and 26, and divide equally upon the plan used before, square off, and transfer to drawing.

The strike and bottom scales on rod and drawing are now complete, except that on the bottom scale faces of the rod should be marked the distance at which they are placed below the strike line.

In the event of accidental destruction of drawing and other details, the whole can be recovered from the rod so prepared.

These scales must now be united by carefully ruled fine lines; these may extend (in the lower half of the instrument) right from the bottom to the top of the drawing, but for the upper sections half-way down will suffice.

The best method of ruling is to use two of the needles, one placed in each scale, with the straightedge touching both, and weighted down to prevent moving.

The pencil should have a touch on the glass-paper for every two or three lines.

Preliminary to measuring the string lengths, the striking proportions must be calculated.

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Allusion has been made to certain undesirable overtones and to a way of securing their absence.

Dr. Young, a celebrated scientist, made the discovery, early in the last century, that an overtone can be eliminated by making the place required for one of its nodes, i.e. place of minimum motion, the point in the length of the string at which it is agitated, thus compelling that point to be a place of maximum motion.

The chief objection is to the eighth overtone, which, as before said, makes a clashing discord with the fundamental, and at the same time the sixth is not wanted to be very prominent. So advantage is taken of what has come to be known as "Young's law,' and by striking the middle and lower notes at one-eighth of their length, we avoid these disagreeable components.

Some careful experimenters throw doubt upon the invariable operation of this law *during the whole period of the sounding of the string*, and my own experiments seem to justify the doubt; but there can be no question that by this procedure the difficulty is reduced to quite tolerable limits.

Above the middle range, piano strings grow rather too stiff to divide into vibrating lengths so short as to allow the full development of these high partials, and so, as regards the upper half of the compass, "Young's law" ceases to be law to us, and other considerations are allowed to rule. One is that of resistance to the blow of the hammer.

Experience shows, that striking on a more resisting part of the string from the middle C upwards, results in much better tone; and when the top octave is reached, this reason is joined and reinforced by another, viz. that in proportion to the distance from the upper bridge, at which the hammer strikes the string, the blow becomes audible by the thud of its impact being returned by the sound-board. These reasons demand a graduation of the strike proportion, ranging from one-eighth of the string's

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length at C, No. 40, to about one-fourteenth at C, No. 88.

An arrangement fully justified by experience gives, from A, No. 1, to C, No. 40, one-eighth; at C, No. 52, one-ninth; at C, No. 64, one-tenth; at C, No. 76, one-twelfth; and at C, No. 88, one-fourteenth of the speaking length of the respective strings. Sometimes due to special circumstances No. 88 may need to strike as near to the bridge as even one-sixteenth of the string's length. Were the scale not broken by the bars, these indications would suffice to define the curve, ruled by a spring lath bent to touch the measured points. This course is, however, inadmissible, although sometimes followed.

The curve should be broken at each bar. That this may be properly done a full table is given of the strike measures of the notes, graded as above, reading downwards from C, No. 88, to C, No. 40.

TABLE No. V.

STRIKE LENGTHS IN MILLIMETRES.

No.	C	B	A♯	A	G♯	G	F♯	F	E	D♯	D	C♯
88	3·85	4·12	4·38	4·68	5·06	5·34	5·70	6·08	6·50	6·95	7·44	7·95
76	8·50	9·16	9·70	10·40	11·15	11·95	12·75	13·70	14·65	15·90	16·80	18·00
64	19·25	20·25	22·00	23·00	25·00	26·50	28·00	29·50	31·50	33·50	36·00	38·50
52	40·50	43·50	46·50	49·00	53·00	56·00	59·00	64·00	68·00	72·00	76·50	81·00
40	86·00	—	—	—	—	—	—	—	—	—	—	—

These lengths should be measured from the strike line as accurately as possible.

Absolute accuracy can only be attained by the use of a slide gauge with vernier.

When the points are marked, a curve drawn with a spring lath or shaped template should touch each one.

It will of course be understood that Table No. V is adjusted to the string lengths given in Table No. III, and not applicable to others.

In Chapter II it was said that in this connection it

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would be shown that the proportion of the string's flexibility, which should be for each descending octave as 2 : 1, is restored, although the strings themselves grow stiffer.

The explanation is, the most flexible position on a string is at one-half its length, the least at one of its ends, and proportionally at intermediate distances.

The grading of the strike proportions is adjusted to, and compensates for, the increases in the stiffness proportion.

The string lengths may now be measured in, upon the drawing, each from the point where the upper bridge curve cuts the centre line of the note.

There are two easy ways of doing this : either lay the scale rod itself upon the drawing, making the notched datum tally with the upper bridge position, and prick off each length upon its respective line, or use dividers for the short notes and the proportionals (Fig. 6) for the longer ones.

The notched recess at the datum mark on the rod, is for one point to go in, so that the whole attention may be given to the other.

Let this operation be carried down to C, No. 40, or whatever other note is to be the lowest of standard scaling.

A curve has now to be ruled in each section through these marks, and if all has been accurately done, a spring lath or shaped template will touch every mark ; should there be any sensible discrepancy, the cause must be discovered and remedied.

What was said about the upper curve applies here also ; do not attempt a curve which will go through the separations for the bars.

The lower end of the speaking length of No. 27 has now to be fixed.

Measure vertically 5½ in. from where the upper edge of the belly slip will come, say, 6½ in. from the bottom line, and make a pencil-mark.

The difference in length of this note from the lowest included in the standard scaling must be

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divided among the others intermediate, so as to make a curve which will follow that already made, but with rapidly decreasing radius, so that the necessary shortening from standard lengths may be as little as possible in the upper notes included, throwing the difficulty of adjusting diameters to length and tension as low as possible.

One used to the task can almost see the required curve and draw it freehand.

The proportionals will now measure the strike lengths of these notes.

Just put the long points to the strike line and the bottom mark, lock in the stretcher, turn over and mark for the upper end.

When the place is reached at which the striking position has been raised follow the new line.

The result will be an easy curve, harmonious with that already ruled.

Should Nos. 27, 28, and 29 not quite conform, compromise just a little.

Mark those lengths which have been omitted on the scale rod, the lower part of which should then look something like the upper part reversed, with the spaces closing more and more rapidly as the strings lengthen, but without perceptible failure of regularity.

Let No. 26 be marked on the rod just as though it was in the same gradation; this can be done to the eye.

The length of the lowest note is affected by the question whether the bass bridge shall be suspended. If yes, the length indicated in Fig. 7 is quite permissible, which is 110·2 cm. against 95·8 cm. for No. 26.

This may be regarded as a generally serviceable ratio for bass notes, being as 15 : 13.

Should, however, a suspended bridge be negatived, it would be necessary to reduce the length of No. 1.

There is no established rule as to the relative length of bass strings.

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Bass bridge lines are not always curved, but if either of them is, the other should be, or the strike proportion will be marred.

The speaking lengths in this section must have their lower ends defined by a line, straight or curved, drawn between the points fixed for 1 and 26, and then by using the proportionals as before, the proper line for the upper bridge can be found.

The question which next arises, relates to the form of the upper bearing, for upon that depends the squaring off of the lower end of the speaking length of each note.

If studs (agraffes) are intended, they are set with their ridges rectangular to the lines of the centre strings, and therefore the notches on the belly bridges are set to follow them.

A handy appliance for squaring off from centre lines is shown in Fig. 6F; this is made of thin metal.

To use same, set the points of a pair of dividers about 4 in. apart, and with the points on the line, one of them about ½ in. from the intersection of centre line and curve, place the inner edge of the tool against the two points and slide it up or down to the intersection, and mark the square line.

This operation carried throughout gives the lines for the pins and notches of the long bridge.

Now come into play the forks to mark the places for the bridge pins.

Usually in overstrung pianos three should be used, trichord of varying widths. The width of the largest depends in part upon the angle made by the lower strings of the middle section.

If the angle is as advised, a width of 12·5 mm. will not be too great; the other two should be about 10·5 mm. and 9 mm. respectively from one outside point to the other, and the three should be used in nearly equal proportions—thus the widest should be used for 18 notes and the others for 22 each.

Mark all the notes as though for trichord, and when the number of bichord spun notes is decided upon,

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just omit (for those notes) the middle strings and their adjuncts.

The bichord notes on the bass bridge should be marked so as to be rather wider at the bottom than the spaces between them; not very much however, the intention being to secure equality of spacing in the middle of the length.

The widening of the lower end opens the middle of each note somewhat, and reduces the risk of jangling under heavy playing.

The actual width, however, depends upon the space allowed for the whole number.

If the width for the section is as that shown in Fig. 7, that of each bichord note at the bottom will be about 8 mm.

To mark bichord notes, on the drawing, a three-pronged fork should be used, so as to secure the relation of the strings to the centre lines, and only the outside marks regarded.

The outside lines for the bridges can now be found, and the bridge templates made.

The writer's way to get the upper margin line is to set a small pencil compass to a radius of 3·5 mm. and make short arcs from the bass side pin-mark of each note, and then shape the edge of a template to touch them all.

The curve is of course broken at the bars and the outer line must be joined at these places by a shape as easy as the differences will permit, but no compromise of string lengths should be made.

When the one edge of the template has thus been shaped, gauge a line to follow it at $1\frac{3}{16}$ in. distance.

Cut and carefully finish this edge.

Lay the template on the drawing in its proper position, and pencil in the top and bottom edges.

Caution should be observed in making the long bridge template. Its curves, of necessity, make some part of its length come across the grain of the wood if it is made of one piece. A better way is to half lap two or even three pieces together, avoiding

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as far as possible crossing the grain. Such a template will stand vastly better than one made of a single piece.

There are now three bridge curve lines upon the drawing, the two outsides, and one which passes through the marks for the centre upper pin of each note.

A fourth is required to define the position of the centre bottom pins.

Make a short gauge-piece of wood just as thick as the distance between the two upper lines, and apply same on each centre string line, measuring from the bottom curve and parallel therewith.

Make short marks on the string lines, and the places for the bottom centre pins are located.

There is now only to square off from these intersections, and the lines of the bottom notches parallel with the upper ones are fixed.

With the same forks as used before, prick in the pin positions.

The lines and notches for the bass bridge can be found in the same way.

It will be noticed in following the above plan that the two upper lines on the long bridge are a trifle nearer together at the treble end than at the other; this may be disregarded in marking the lower centre pin position, or a similar approximation may be made by two very slight reductions of the gauge as the marking for the bottom centre pin advances from the middle towards the treble end.

To mark the lines for the bearing part of the studs at the wrest-plank end of the strings, use the square as before, applied to each intersection of centre line with bridge curve.

There is no great variation in the dimensions of studs for upright pianos.

The standard seems to approximate to 11 mm. diameter, and from the circumference to the apex of the bridge portion 1·75 mm.

This means that the point to be marked for the

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centre of the stud, is 3·75 mm. above the bridge line, and on the centre line of the note.

This distance should be carefully marked, and from it, in each note a circle placed of 5·5 mm. radius, and when all is finished the studs should look like those in Fig. 10.

The centre dots will be used when working templates are pricked off, to locate the places in the iron frame for the tapped holes, into which the studs are screwed.

The stud upper bearing, while not without disadvantages, is on the whole the best.

It permits both ends of the speaking length of the note to be squared off, so that the three strings are of the same length and have the same strike proportion.

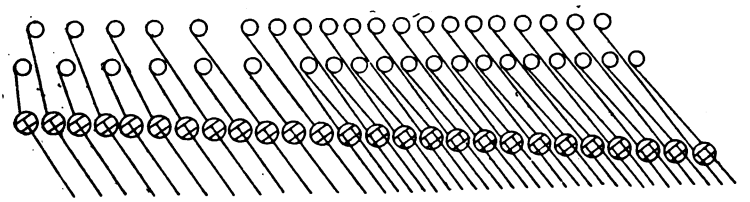

FIG. 10.

It accurately fixes the angle of the down bearing, and permits a nearer placing of the lower line of wrest pins than if a pressure bar is used. Also, being of brass, it is not so hard as an iron bridge, and the rounding of the edge of the bearing part is always worked to the same radius, about $\frac{1}{16}$ of an inch.

On the other hand it is somewhat expensive, both in the cost of the studs and in fixing them.

The holes in the iron frame have to be drilled and tapped, then the studs must be carefully fitted to screw tight home to the right position, and additionally the stringing operation is more difficult.

So, on the whole, there is no cause for surprise that only makers of very expensive pianos are willing to use them.

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It seemed right, however, to include the above information as to procedure in drafting, lest some reader should require it.

The choice of one of the other forms of upper bearing whether iron bridge or embedded wire *should* affect the notching of the belly bridges, but unfortunately the proper adjustment is not often made.

The strings forming a note should be of the same length, which they cannot be unless the lines which define the ends of the note are parallel, to secure which naturally the line of the notch on the belly bridge must follow that of the top one.

Is inequality of length of importance?

The law of the relation of tension to length is: "The tension varies as the square of the length."

Let us suppose that we are dealing with C, No. 52, of length 36·4 cm. and tension 173 lbs.

The centre string *is* of that length, but the one on the treble side is 1 mm. shorter, and that on the bass side is the same amount longer.

The tension of the short string will drop to 172 lbs., while that of the long one will rise to 174 lbs., a difference of 2 lbs. in the tension of strings forming the same note. So, manifestly to make them parallel is worth a little initial trouble.

It can be done thus:—

Use a fairly wide straightedge with its ends made absolutely rectangular to the edges.

Place one end true to the short part of the curve of the upper bridge occupied by the width of the note.

The edge of the ruler will then usually diverge considerably from the line of the centre string.

Weight down the ruler to prevent its moving; and from it, with a set square, mark off the notch, cutting, as in the former case, the intersection of centre line and curve. The notch lines are now parallel to the upper bearing, and consequently the strings are of equal length.

The marks for the lower notches must of course follow the lines of the upper ones.

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This is the only change in procedure as affecting the belly bridges.

There is now to mark the scales for wrest and hitch pins, and to allow the former to be done it is necessary to decide the form of the bearings which shall be used at the bass upper bridge.

The pinned wooden bass bridge is antiquated and will not be considered.

The pinned iron bridge requires a side draft, which removes the need for a pressure bar.

The embedded wire bearing (once very popular) is not frequently used in the bass section. In the case either of wire bearing or studs, the greater number of the strings go in one line from the belly bridge to the wrest pins, which are then usually placed in two rows, for the angle made by the strings almost precludes the use of four, except at a considerable expenditure of space.

With the wire bearing a pressure bar is needed.

With the pinned bridge, the strings have to make two angles at the point of contact, one backward and one toward the right hand.

The sum of these angles should not be less than 20 deg., viz. 5 deg. backward and 15 deg. to the right.

In this case because of the near approach of the portion of the string above the bridge to the vertical line, it is easy to put the wrest pins in four fairly close rows.

In the case of a wire bearing, provision for side draft has to be made for a few of the lowest notes, which cannot be permitted, for lack of room, to continue in the line of the speaking length beyond the bridge. This can be done by placing long, rather stout pins just above the bridge and below the pressure bar, and it is also convenient to put pins as shown (Fig. 11) between the two strings of the bichord notes to maintain them in position.

Many years ago a German house introduced a pin intended to fulfil both this purpose and that of the pressure bar, it being drilled across, and a steel bar

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driven through, under which the strings passed, but this was not regarded with favour. A considerable number of pianos have been made with the bass section as per Fig. 11. The stud in itself fulfils the intention of all these expedients, and is sometimes used in the bass part of upright pianos with other forms of bearing in the remaining portions, and this is, in a way, a partial imitation of the usage now common in grands.

The passage of the outside strings of each note from the bridge to the wrest pins cannot be parallel.

This rule holds throughout the instrument, but is most pronounced in the lower part of the middle section. The lines of each note have to meet at a point not a great distance from the bridge, and in the part

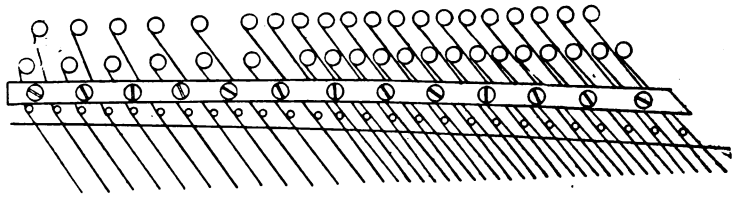

FIG. 11.

just mentioned the meeting sometimes has to be at, *or even under*, the line of the top row of wrest pins.

With every care used it is only just possible to make the bass side string of each trichord note clear the coil upon the wrest pin of the treble side string of the note below it.

It is sometimes overlooked, with serious consequences, that clearance must be provided for the wrest pin, *surrounded by the wire*. The measures included are: No. 0[1] wrest pin 6·85 mm., No. 20 wire 1·125 mm. × 2 = 2·25 mm.; in all 9·10 mm., radius 4·55 mm. With this caution noted, we can proceed with the wrest-pin positions for the middle and upper sections.

[1] There is some variation in the marking of wrest pin gauges.

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Allowing proper room for the pressure bar, if one is to be used, begin with note No. 27, and measure and rule in, the six lines upon which the pins of the trichord notes are to be marked.

These lines are usually set a little wider apart at the treble end, and are mostly curved; a regular gradation from 8 mm. to 12 mm. is convenient. These lines must be in all parts equidistant.

Let the widths of the notes now be marked on the bridge line, usually 5·5 mm., at the lowest part of the middle section, increasing to 6·5 or even 7 mm. at No. 88. This produces equality of width at the hammer line. This gradation cannot be made in the case of studs, with their fixed width.

It is supposed that it has already been decided, by calculation upon their length, how many notes upward from No. 27 are to be bichord with spun strings.

We will suppose the number to be four, and that the lowest note with three strings is D♯, No. 31.

Draw upward, from the bridge line, the outside strings of this note, making them meet the centre line at the point where that intersects the top wrest-pin line. Do the same with Nos. 32, 33, and 34, not making heavy marks, lest they have to be erased.

Set off on the treble side of each of the three strings of each note, the radius of wrest pin and coil upon the proper lines. Lightly run in with a pencil compass the circles of the lowest row. Do they just clear the next strings? If they do not, the meeting-point must be still lower. Try the four top notes in the same way. Here the coil radius may be reduced to 4·25 mm. and the experimental point for the meeting of the lines may be tried, say, 3 in. higher.

If this proves the correct position, unite the points of intersection thus found, by a line conforming to the curve of the wrest-pin lines, and make the place where this line cuts each centre line, the meeting-place for the lines of each note. The whole of the outside lines can now be put in, the radii pricked off, and

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the circles all lightly marked in pencil. Let the wrest pins of the four bichord notes be upon the four lines as shown in Fig. 7, but except for the omission of the centre strings, &c., treat as the others.

In placing the wrest pins in the bass section the same considerations must rule, and the same methods be followed. If studs or brass wire bearings be intended, the string lines for all except a few of the lowest notes must follow the speaking length through to the wrest pins with such drawing together as may be required for clearance.

In this case the pins are in two rows. Turn the line for the lowest note as much to the right hand as necessary for its wrest pin to clear the bass bar, measure the distance to the natural position of the sixth or eighth note, and divide the amount equally; mark the divisions, and rule up from the line from which the string bends.

If, however, a pinned bridge, be chosen, the centre lines of the notes must *all* be turned, as before stated, 15 deg. to the right hand, and the wrest pins can stand in four lines, with those for the single strings on the two inner ones.

In marking for the pins on the iron bridge, it is necessary to set off the centres, the semi-diameter of the pins to the right-hand side.

This is not required on belly bridge.

The Position of the Hitch Pins.—Theoretical considerations would warrant the supposition that the length of spare wire between the belly bridge and the hitch pins, should double in each descending octave. There must certainly be a minute rocking action of the bridge (proportional to the transverse motions of the strings) by which the effect of those motions is conveyed to the sound-board, and as the extensions and shortenings of the strings are doubled octave by octave, and as the wire length between the bridge and the hitch permits an elastic action, it would seem, a priori, that corresponding provision

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should be made. Experiments, however, fail to demonstrate an advantage, and, however desirable it might be, this course would be prohibited by lack of room.

It may be that the action referred to is so exceedingly minute, as not to be appreciably affected by the spare portion of the wire.

Naturally, because of the curves of the respective lines, these spare portions do increase in length as the lower tenor is approached, even if the distance separating the lower line of the bridge from the upper one of the hitch plate is made equal throughout.

There seems no real reason to diverge from the common practice of making the distance between these lines increase slightly in their progress downwards. A reasonable plan is to make that distance about $1\frac{1}{8}$ in. at top C, and increase to $1\frac{3}{8}$ in. or a little more at middle C, both measures being made on the shortest path between the lines, and let the curve of the hitch plate run with that of the bridge.

Let the width of the hitch plate be about $1\frac{5}{8}$ in. throughout.

Within these lines, and following their curves, place two others, one $\frac{11}{16}$ in. from the upper one and the other $\frac{7}{16}$ in. from the lower one; on these two lines the hitch pins are to be placed.

It is presumed that the 35 notes included in the two upper sections will be hitched in the ordinary way, with three hitch pins to each two notes.

To place these, take the same forks as used to gauge the widths of the notes on the belly bridge, and mark on the bottom scale corresponding widths.

Rule between these two sets of marks across the hitch-pin lines, alternating each pair, and in the centre of each pair put a needle-prick for the centre of the pin.

The upper section contains 18 notes, and therefore requires 27 pins.

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The next section has 17 notes, and so there will have to be one with two pins placed for loop and eye.

This section will therefore require 26 pins—24 for 16 notes and 2 for the odd one.

The middle section—27 notes—has now to be provided for. The tables of lengths and tensions show how important it is to be able to treat the lower notes in this section individually; in Table No. IV there are five instances of this need to string notes separately according to tension.

Therefore let each note be provided with two pins, so placed that the middle and right-hand strings loop upon one, and the left-hand string hitches upon the other with a German eye. In placing these, see that the one comes central to the pair of strings, and that the other is set off a bare $\frac{1}{16}$ in. to the bass side of its string.

For all *spun* strings the pin is *on* the string line, because twisted eyes are central, but for German eyes the above set-off is needed because the eye is not central to the string.

Before placing the pins for the notes 27–31 the stringing must be calculated according to the method shown in the tables, so as to determine how many of these must have spun strings.

The hitch plate for the bass strings may be placed at any convenient distance below the bridge, and may be $1\frac{3}{8}$ in. wide.

Place the top line of pins $\frac{1}{2}$ in. from top edge of plate and the lower line $\frac{3}{8}$ in. from the bottom edge; both lines are to be used for the bichord notes, and the bottom line only for the single strings, of which 12 is a convenient number.

The standard gauge for English hitch pins is $\frac{5}{32}$ in., and to represent these the compasses would need to be set open $\frac{5}{64}$ in., but the writer prefers to follow the same rule as for wrest pins—viz. show the surrounding wire.

In that case, the radius for the lower notes is thus:

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pin 4 mm., No. 20 wire 1·125 mm. × 2 = 2·25; in all 6·25 mm., consequently radius 3·125 mm.

It is not easy to be quite exact in dealing with such small dimensions, and as there is a reduction toward the treble end as the diameter of the wire decreases, it is best to take a radius of 3 mm. and use same throughout.

The Iron Frame.—In a following chapter, "Strain-bearing Structures," some of the less obvious but very interesting facts concerning the frame are discussed. For the present we merely deal with its front elevation, which is all that should be included in a scale drawing.

An important point to remember is that all face dimensions should be shown at their fullest.

The portions which project, are smaller in the front than they are at the back. This is explained under "Contraction Drawing." The various positions for the vertical bars are indicated by the items already placed.

Head Bar.—This is a strip along the top of the wrest plank, and may be shown $\frac{5}{8}$ in. wide. It must be so placed as to clear nicely the highest of the wrest pins with sufficient room for the pipe of the tuning hammer. The two lines for this may be at first ruled right through, although there will be portions not included in the finished drawing.

The Treble Bar.—This is rectangular with the head bar, $\frac{1}{2}$ in. wide, and so placed as to have its outer edge $\frac{1}{8}$ in. within the case, and therefore $2\frac{7}{8}$ in. from the centre of the top note; it may be carried down to a convenient point where a screw can be placed, below the part where the sound-board is cut off (see "Sound-boards"), and finished with a screw boss (see Fig. 7).

The upper part of the bass bar may next be placed. This is of the same width, $\frac{1}{2}$ in., and must be so placed as to safely clear the wrest pin of the lowest note, and leave $\frac{1}{8}$ in. between its outer edge and the bass end of the case, which will be $4\frac{3}{8}$ in. from the centre of the

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note, measured along the strike line, and therefore the outer edge of the bar is $4\frac{1}{4}$ in. from the same point.

This upper part is rectangular with the head bar, and from it depends the bass bar proper. This may be shown full $\frac{5}{8}$ in. in width; it meets the upper part just at the bridge line and runs to the bottom at an angle similar to that of the lower strings.

Great care is needed in positioning this bar in relation to the string of A, No. 1. The excursions of this string are very wide; and nothing should be nearer than $\frac{5}{8}$ in. from the centre of its thickness at the middle of its speaking length, and therefore it is wise to let the bar stand a little nearer to the vertical line than the angle of the string is.

The first intermediate bar runs on the left-hand side of note No. 27, and should be shown $\frac{5}{8}$ in. wide from the strike line downward, $\frac{1}{2}$ in. wide at the strike line reducing to $\frac{3}{8}$ in. at its union with the head bar. This bar also may diverge slightly from the line of the strings of note No. 27 so as to allow a trace more room in the middle. A short bar is shown (Fig. 7) extending upward from the bar just described and making a union with it just below the strike line.

This runs nearly with the slope of note No. 26. It is not of much real service, but contributes to the appearance of strength, and provides at its union with the head bar another screw or bolt position.

This should be $\frac{1}{2}$ in. wide at its union with the other bar, and reduce to $\frac{3}{8}$ in. at the head bar.

The Knee Bar.—This runs vertically between notes 53 and 54, until in its descent it approaches the strings of note No. 26, when it turns to the right and runs with the line of this note to the bottom.

This bar may be $\frac{5}{8}$ in. wide at the bottom, reducing to $\frac{1}{2}$ in. at the strike line, and further reducing to $\frac{3}{8}$ in. at the union with the head bar.

The bar between notes 70 and 71 may be of the same dimensions: this continues downwards, until it meets the knee bar.

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Where these two bars have to pass between the wrest pins, there is not enough room for them to be vertical.

All difficulty can be avoided by making them follow an oblique direction with the wrest pins, from a point a little below them, to the top. This throws the bars a small amount to the left hand at the top and a little to the right at the bottom of the wrest-pin lines.

It should be noted that the bar widths here specified are intended to be used with proportionate depths, as stated in the chapter on "Contraction Drawing" and shown in Fig. 12.

The arches and belt may now be drawn in.

The line of the tops of the arches should not be nearer to the strike line than $\frac{7}{8}$ in. and the radii on which the arches are struck should not be small.

The proportions shown in Fig. 7 are safe for a frame which has a full wrest-plank plate.

The top edge of the main belt is already defined by the line of the hitch plate, and the lower edge can be made harmonious with it.

The width should in no part be less than $3\frac{1}{4}$ in., with all corners and unions liberally stiffened with gussets, as shown (Fig. 7). In determining the lower edge of the belt, regard must be had to the requirements of the bass bridge. If this is to be suspended, room for the top of the suspension must be allowed.

Wherever convenient, there should be flanges to the bars; the backs are subject to a tensional strain, and in this respect cast iron is not as strong as could be desired.

Flanges are not shown in the illustrations on the bar which crosses the tenor strings; they can only be put upon the back edge, at which part this bar is in compression, and where, therefore, they would not be of value. (See further on this subject "Strain-resisting Structures.")

Sometimes this bar cools in considerable strain, and it is not easy to see why it should do so.

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The piercings in the webs under the hitch plates may now be put in and all the little arcs where otherwise there would be sharp corners.

Screw Positions.—In the lines of the centres of the four intermediate bars, at their intersection with the head bar, put in circles of $\frac{9}{16}$ in. radius struck from centres placed $\frac{11}{16}$ in. below the top of the head bar and then put in arcs of $\frac{5}{8}$ in. radius to represent the bottom dimensions of screw bosses.

Treat the corners in a similar manner, centering the circles equidistant from the outsides of both head and vertical bars.

As before said, the lower end of the treble bar is to finish with a screw boss at a convenient place: this will be about $12\frac{1}{2}$ inches below the strike line. Make the gusset under the belt unite neatly with this boss.

Draw the lines for the pressure bar and mark for its screws.

Also mark for all screws holding frame to wrest plank.

Upon the presumption that the bottom board of the case will be fixed in the usual English manner, and that it will be $1\frac{1}{4}$ in. in thickness, rule a line above the bottom line extending from the lower end of the bar which runs with No. 27 to the end of the knee bar. It will be noticed in Fig. 7 that a space is cut out of the middle of this piece: the object is to permit the insertion of a piece of wood to stand in line with other pieces beyond the ends of the frame, so that the bottom board may be securely glued.

This method of fixing the bottom edge of the frame, allows the sound-board to be somewhat larger under the bridges than would be otherwise possible.

In each of the $1\frac{1}{4}$ in. plates thus defined, put three screws $\frac{1}{2}$ in. from the bottom edge.

Above the line last made, run others $\frac{5}{8}$ in. from it uniting the hitch plates each with the next bar on the right and finish with arcs. (For the purpose of these see sections in Fig. 12.) Make provision for a pillar

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where the two bars in the bass make a cross, and also for another in the belt, somewhere between the knee bar and the next above it.

These frame directions seem very complex, but can easily be followed by reference to the illustrations.

Belly Bars.—The positions of these must be decided and shown.

Their functions are discussed under "Sound-boards," and therefore will be excluded here; all that need now be considered is their number, widths, and distribution.

We will assume the number to be eleven, and the widths as per suggestions in "Sound-boards."

The positions have to be found thus:—

Draw a diagonal line passing as nearly as possible equally through the curves of the long bridge. This represents the direction of grain of the sound-board most in favour.

The bars should be placed at right angles to this line.

The lowest should be so positioned that note No. 27 is just over it, at the place where bridge and bar cross, the highest; so that notes 84 and 85 sit upon it.

If possible each end of the bass bridge should also rest upon a bar.

The breaks between Nos. 53 and 54, and 70 and 71, should either be crossed by bars, or else each break should be midway between a pair, with a hardwood strap following the lines of the bridge glued upon the back of the belly and uniting them; this plan is, on the whole, preferable.

Keeping these particulars in view and being careful not to put pillars where they will cut bars, distribute the remainder so as to divide up the spaces as equally as possible.

Back.—The general subject is treated under "Strain-bearing Structures."

It is only necessary in the scale drawing to show a few main lines.

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First a line $\frac{1}{8}$ in. above the head bar, and then vertical lines $\frac{1}{8}$ in. outside the end bars.

Bracings.—The strength of these is not very important in a piano with a properly designed iron frame; indeed as strain bearers they might be eliminated, but it is not easy to convince the lay mind of this, and so although not really necessary, let there be four or five of them. Two of them must be placed so as to stand where they can receive the pillars. If the distribution can be equal, it helps economy in manufacture.

In this country for very many years bracings have been got out of 3 in. × 9 in. spruce halved, and aforetime were always placed on edge, but the wider space now required between them and the belly, to accommodate the diagonal barring, has led to them often being placed on the flat, in which case they show about $4\frac{1}{8}$ in. wide, albeit they are sometimes got out of smaller section stuff. Whatever the width is to be, put in the lines, let them extend right to the top, for reasons of which see chapter on "Strain-bearing Structures."

Bottom piece.—Represent thickness of this, and if the bracings are tenoned through, indicate the tenons.

Bass and treble corners of belly. The reasons for removing portions are given in Chapter on "Sound-boards"; show the limits of these places. Show the lines of all belly fixing slips or fillets.

Wrest-plank Rebate.—The projection which provides this, should be so placed that the upper bridge at the treble end sits fairly over it, so as to give the most solid possible resistance to the blow of the hammers.

The ridge should be about $\frac{5}{8}$ in. thickness where it joins the back of the frame, and therefore its top edge will be about $\frac{3}{8}$ in. above the strike line and its lower edge about $\frac{1}{4}$ in. below the same. Put in these lines. The upper one also defines the lower edge of the wrest plank.

The upper edge of the web which is cut away to

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receive the crossing of the wrest plank, must be defined.

The only considerations which need affect the decision are, to secure as much wood as possible below the wrest pins, to avoid coming too close to the bridge at No. 27, and to make the lines so that fitting of the crossing shall be easy. (See sections in Fig. 12.)

Inking.—There will seem to be a great tangle of lines upon the paper, but the items can easily be sorted out.

There are four layers of drawing, and each is to be finished in a special colour independently.

The lowest is the back. Let all its items be green, and treated as though it were alone, visible parts in solid line, hidden ones in lines broken into dashes, according to the ordinary rules of draughtsmanship.

The next layer is the belly, which must be treated in just the same way, using red ink.

The third is the iron frame, including the pressure bar and screws, or studs, as the case may be; let these all be in Indian ink.

The fourth and last layer is the strings. Ink the portions as shown in Fig. 7, using blue for steel; but where a spun portion of a covered string is shown, as at Nos. 1, 16, and 28, let red be used as indicating copper.

Do not ink more strings between the bridges than just the centre line of each C, so as to make it easy to trace the upper and lower details of the notes.

If not accustomed to inking drawings, be cautious as to blots, and to have the chamfered edge of the ruler to the work, or the ink will inevitably run under.

Do not dip ruling pens into ink, but use a quill filler.

After the erasure of tentative pencil-marks with soft rubber, and a general clean up with stale bread, the layers of drawing will be easily distinguishable.

Reasons are given in the chapter on "Sound-

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boards" why the down bearing on the belly bridge should not exceed about $1\frac{1}{2}$ deg. in the middle, graduating to 1 deg. at each end.

Mark these angles by the side of the centre string of each C, starting from the upper notch line, and reaching to a point midway between the hitch pins.

The distance of the line from the centre line at this place is the height of the gauge-piece to be used by the "marker off," in "taking the bearings."

Should the measurement of these angles present a difficulty the following will remove it :—

Draw a straight line of indefinite length, and from a point in it another, making an angle which at $6\frac{5}{8}$ in. distance from the point of intersection, places the lines $\frac{1}{8}$ in. apart. The resulting angle is approximately 1 deg.

The particularity of the directions given in this chapter, and in that on the "Contraction Drawing," may seem to one accustomed to such work exaggerated, and some of the methods of securing accuracy needlessly elaborate.

It should be remembered, that while it is hoped that even experienced scale draughtsmen may find in this work useful information, it is the tyro who is in the author's mind throughout.

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CHAPTER IV

CONTRACTION DRAWING FOR IRON FRAME

THIS is a drawing of the iron frame only, expanded 2 per cent, and showing all section details.

Professional pattern-makers are so skilled in allowing for the contraction which takes place when molten iron solidifies, that they can work from a drawing of standard dimensions almost as easily as as they can from a special contraction drawing.

Pianoforte makers, however, while able to make patterns as well as they can be made (as regards workmanship) find the task of calculating contractions, while the work is in progress, a heavy addition, and for them a proper contraction drawing is of advantage far beyond the trouble of making same.

In making patterns for piano frames, two contractions have to be provided for, because the wooden pattern is used only to enable a durable iron one to be cast, which, when smoothed, is the permanent form for the iron moulder.

Thus arises the need for double allowance, one between the wooden model and the permanent iron pattern, and one between that and the finished frame.

The amount which iron contracts, varies somewhat with its quality, and also with the masses of metal, and so there is no absolute rule applicable to all sorts of castings, but for the high quality of iron required in piano frames, and for the customary dimensions of these, about 1 per cent suffices, so that the dimensions shown on a contraction drawing must exceed the actual ones by 2 per cent measured from some one point.

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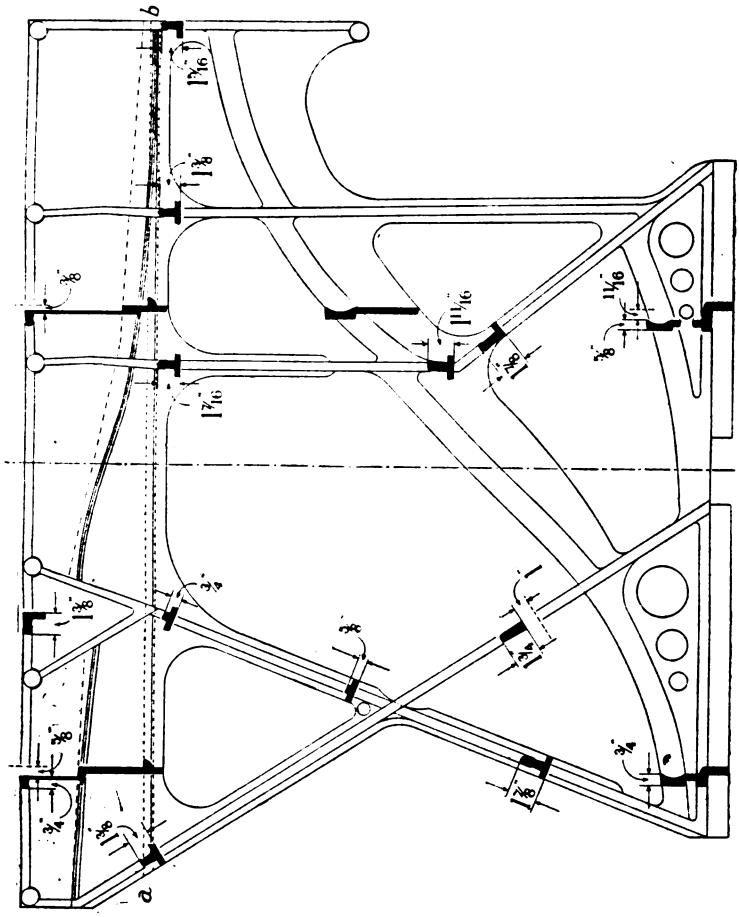

FIG. 12.

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It does not matter where this point is located, provided that all measures are taken from it.

The writer, who has personally made many frame patterns, finds it most convenient to use the strike line and the vertical centre line of the scale drawing, as data for these measurements, which is the same as using the point of their intersection.

It is only necessary to provide for contractions of face dimensions; thicknesses and depths should really be made a little bare, the reason being that when the pattern has been closely embedded in the sand mould, it has to be shaken by rapping, in order to loosen it, so that it may be withdrawn without damage to the mould, this causes an increase in depths and thicknesses, of bars and plates.

So a contraction drawing should show all face measurements expanded but all *sections* either just normal or a trace bare.

The easiest way to make a regular expansion is to rule upon the scale drawing, a series of horizontal and vertical lines, measured from the strike line and the central one, dividing the whole into 14 cm. squares.

It is better in cases of successive dimensions to always measure from the starting-point, and not from the last marks made.

Then, on the sheet for the contraction drawing, mark the strike and central lines, and divide up in a similar manner, using the 2 per cent contraction rule, or if one is not available let the lines be 14·3 cm. apart, which gives the same result.

A large number of measure points is thus provided, and by the use of the 2 per cent rule and proportional compasses (Fig. 6E), all lines, curves, or centres of circles may be quite accurately placed.

Use the short legs of the compasses to obtain the measures from the scale drawing and apply the long ones to the work in hand. Each position must be measured from a horizontal and from a vertical measure point.

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The widths or thicknesses of bars specified for the scale drawing assume that the sections shown on Fig. 12 will be used with them. The reasons which govern these particulars are set forth in "Strain-resisting Structures."

The flanges and arches are all formed out of a plate or web (see Fig. 13). This is of $\frac{3}{8}$ in. thickness throughout and the back of it is the surface from which all the sections shown in Fig. 12 are measured.

This plate extends from $1\frac{1}{4}$ in. above the bottom of the frame up to the unequal line near the top, where it is cut away to provide the abutment which meets a crossing layer on the wrest plank as shown in dotted line.

"Draw."—This is a term used to describe a tapering of all parts which, without this provision, would destroy the sand mould when the pattern is extracted from it.

The more that can be given the cleaner will be the casting.

The minimum possible is said to be 1 in 96, but there is no reason why even three times that amount should not be given in pianoforte frames.

The draw will be noticed on the sections shown in Fig. 12.

It has not to be all one way; the parts which are moulded in the upper box of the iron founder draw in the reverse direction.

These parts include all which lie behind the back of the web, the inside of the bass cupola, and the ends and underside of the bar which crosses the lower tenor strings.

It is a rule that draw for parts which are moulded in the upper box should be greater than for those on the other side, the reason being that there is more difficulty in removing the heavily sand-packed upper frame safely.

This is unfortunate as regards the wrest-plank rebate, which should be rectangular to the back of the web.

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If this ridge can be planed at the foundry, the excess of draw will not be a disadvantage, but otherwise it should be kept as small as possible.

Elevation of Bass Section. — Where the bass strings cross the lower tenor ones, there has to be at the strike line a space between them of $\frac{5}{16}$ in.

This space has to increase as the measure point descends, so that at about 18 in. below the strike line, the distance separating the centres of the strings Nos. 1 and 27 is $\frac{5}{8}$ in.

A trial of lines on this proportion, will show that at 4 ft. below the strike line the centres would be about $\frac{7}{8}$ in. apart.

Not less room than this should be allowed; there is not only the swings of the lowest strings to be considered, but also those adjacent to No. 27; should both be struck heavily at the same time there is danger of contact. The wrest-plank and hitch-plate levels must conform to this.

Some further particulars are noted in the chapter on "Pattern Making."

It is not absolutely necessary to lift the web with the hitch plate upon it, and thereby make a cupola, as shown (Fig. 12), the web may, if preferred, remain on the general level, and the hitch plate be built up to the required height, but the other plan looks better, and is stronger.

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CHAPTER V

PATTERN MAKING

THE making of a frame pattern for an upright piano, by the aid of a contraction drawing is a very simple matter, but the pattern for a grand is much more difficult to make.

The particulars herein given are adapted to the design shown and described in the previous chapters and illustrations.

If some other design has to be made, the instructions are of course only applicable in a general way. The first thing to be done is to select and prepare the stuff for the "web"—a framed-up foundation plate, out of which is cut the flanges, belt, arches, etc.

This should be of either pine or whitewood, $\frac{1}{2}$ in. cut, very dry, and, if possible, on the quarter, for it is required to remain very flat; it should be planed up accurately and gauged rather full $\frac{3}{8}$ in.

A pattern-maker would unite the pieces to form this frame (for the aspect of which see Fig. 13) with lapped joints; but there is a preferable way, viz. groove all the joints with a $\frac{3}{32}$ in. grooving plane, making the grooves about $\frac{5}{16}$ in. deep; and put the work together with hardwood tongues tightly fitted.

When the glueings are hard, finally plane over to net $\frac{3}{8}$ in. thickness.

Then lay upon the web the contraction drawing, and with a fine point prick through all the lines, being liberal of marks in curves, and careful not to omit any corners or other details.

Be very particular to mark *all* the lines which represent the outlines and apex of iron bridges.

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When the contraction drawing is removed, it is wise to go over the marks with a fine-pointed pencil so as to render them easily visible, and where lines are required they should be at once drawn in.

The lines of the arches, belt, etc., can now be cut on the taper and finished. If the aid of a fret sawyer is available, his machine will do this work to a regular bevel and cut so finely as only needing to be glass-papered.

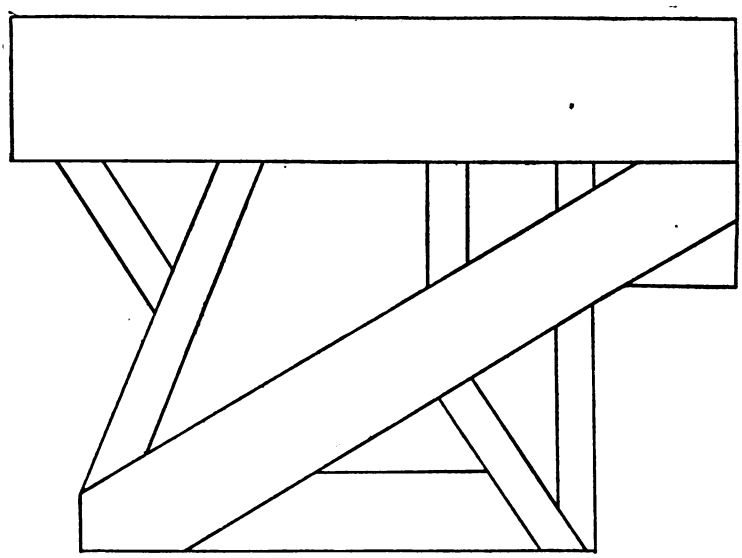

FIG. 13.

To make and place the bridges is perhaps the most critical part of the whole operation.

Place under the web a piece of stuff (beech is best), carefully planed to $\frac{3}{8}$ in. thickness, fasten securely and drill from end to end three rows of very fine holes, quite vertical and right through both thicknesses. The outlines and apex of the bridges are thus defined, and can be cut and tapered, leaving the very apex to be finished when glued home. Drill also a few holes to show (on the back of the web) the position of the rebate piece.

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The wrest-plank plate should be made of most carefully selected wood $\frac{3}{16}$ in. in thickness.

Place this also under the web and drill through the same holes as for the bridges, etc., and additionally, all the marks on the web which will be covered by the plate when in position.

The lower edge of the plate can be cut on the bevel to the lowest of the bridge lines now shown on its face, and it can be tentatively fastened in position by a few small screws placed where the bars will afterwards cross.

The value of the drilled indications will now be realized, for a few fine pins placed in the holes will secure absolute registration.

The bars are best got out minus taper, and the draws made from each side after they are fitted; these also may be held in place with fine screws from the back of the web.

There is of course a joint in the knee bar; this should be forked or dovetailed.

The bends in the two bars crossing the wrest plank between 53 and 54, and 70 and 71, can be made by merely glueing a piece of $\frac{1}{4}$ in. stuff upon the projecting side and carving both sides to shape.

When all the bars which run from top to bottom are thus made and fixed, remove them and make and place the head bar, tapered.

Have turned 7 tapered bosses $1\frac{1}{4}$ in. diameter at the bottom, reducing to $1\frac{1}{8}$ in. at the top, 1 in. in depth, and each with a loose cap piece of $\frac{1}{8}$ in. thickness.

Fit halves of four of these bosses to the bevel of the head bar, and glue them in the proper places to meet the ends of the four intermediate bars, which when replaced must be gouged to fit the curves of the bosses.

The two for the ends must be reserved till the whole frame is glued up, when they have to be fitted as quarters.

The underside of the head bar must be cut to match the three levels required, the lowest being

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between the bars forming the V, the next along the whole of the part to the treble side of the V, and the highest along the bass section.

One of the most critical parts of the whole operation is the cutting out, and fitting that part of the web which is raised to form the bass cupola.

This has to fill a larger place than looks possible, but as the whole of the underside of this part has reversed draw it can be done. Mark for the cuts of its ends nearly $\frac{1}{8}$ in. under each of the two bars between which it goes, and cut out on the bevel with the smallest loss possible.

The underside of the bar which crosses the tenor strings must be so cut out as to fully clear the treble side string of the highest note which goes under it to reach the hitch pin; and the height of its arch, all along, must be as shown in section in Fig. 12, which is $\frac{3}{16}$ in. above the strings which it crosses.

A core block should be made for the place where this bar stands over the hitch plate, and a core box to fit same, but sometimes the ironfounder prefers to supply these himself. Where this bar joins the X the flange of the bar which it meets must be removed for a short distance, as shown in Figs. 7 and 12, and the draw of the part of the flange thus removed must be reversed.

The wrest-plank plate can now be divided. In removing the part between the bars forming the V, the cuts should be made under the bars, and these cut out to fit over the ends of the plates. The bass section of the plate should be lifted to its proper level, by a piece being put along its lower edge, between it and the web. Reasons are given in "Bearings, &c.," showing that this method is much superior to merely raising the bridge to the required height, although it involves a little more trouble.

One particular should be observed, which is however often disregarded, viz. that as the single covered strings are so very thick, and as a straight "blow" line is a desideratum, the bass plate with the

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bridge should recede about $\frac{1}{10}$ in. at the left-hand end to partly compensate.

The top edge of the web may now be cut, and tapered for draw to the back, and the wrest-plank plates glued in position, and all the bars may be also glued after having been tapered.

At this stage great care is required to avoid distortion.

The hitch plates can be pricked through from the contraction drawing; tapered for draw, fitted between bars, and glued home: except that on the bass cupola.

Let the raised web for this be fitted, observing that it must follow the level for the bass strings, for which see section in Fig. 12.

Glue in a piece to fill the gap at the bottom, and put in corner blocks all round the interior, which are afterwards to be carved to hollows. The hitch plate for this section can also be fitted and glued in.

The bridges on the wrest-plank plate can be fitted between the bars, and (using a good many pins to secure correct registration) may be glued, and when dry the apices may be finished.

The quarter bosses in the treble and bass corners may be fitted and glued, and the patteries (which were turned with the bosses) glued on, including that on the boss at the lower end of the treble bar.

The reversed draws on the inside of the cupola, and all other places which have to be moulded in the top box must be smoothly finished, and where top and bottom draws meet, the lines must be nicely defined. The projecting pieces attached to the back of the web, viz. the wrest-plank abutment and the bottom pieces, are fixed and finished last.

It is usual to remove the thickness of the web from behind the knee bar, and the one above it, at the places where they cross the bridge, the object being to reduce the depth of the recesses in the bridge.

This of course weakens the bars at these points, but a choice between evils decides in favour of this

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practice, as even with this thickness removed the cutting into the bridge has to be considerable.

Cornering.

All sharp inside corners are lines of weakness in castings, from which cracks may develop, and must therefore be avoided; such angles must be filled.

There are several efficient ways of doing this, of which two easy and inexpensive ones may be mentioned.

The filler may simply be paraffin wax, melted in, and scraped out with a scraper so formed, as to leave a nice hollow curve.

It is usual to mix black with the wax if the pattern is to be finished black. The wax can be procured cheaply at any drysalters. There is a leather fillet supplied by dealers in pattern-maker's requirements; it is made in sizes ranging from $\frac{1}{16}$ in. to 1 in., and sold in bundles of 50 ft.

It is most beautifully cut, and is simply glued into place, and rubbed down with a piece of wood shaped to fit. It follows easily the various shapes. While a little more expensive than wax, it is much harder, and stiffens a pattern a good deal.

Varnishing.

This is best done with good French polish, mixed with vegetable black, and put on with a large camel-hair mop.

The polish and black must be thoroughly mixed and strained.

There should be several coats put on (each allowed to dry hard) and smoothed with fine glass-paper before the next is applied. To finish with rubber in the ordinary way of French polishing, is said to cause adherence of the moulding sand, and should therefore be avoided.

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The Weight of Castings.

It is not possible to determine absolutely from the weight of a pattern, what will be the weight of the casting.

The weight of wood is very variable. The published specific gravities are only averages.

Castings themselves are not always of precisely the same weight, due to the fact that sometimes the "cope," the upper box, does not shut closely down upon the lower one, and a thick casting results.

However, an approximate estimate may be made thus: divide 7·4, which is about the specific gravity of cast iron, by the specific gravity of the wood of which the pattern is made.

Suppose this to be whitewood with a specific gravity of 0·423, this will go into 7·4 almost exactly 17½ times, therefore for each pound in the weight of the pattern we may expect the casting to weigh 17½ lbs.

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CHAPTER VI

THE SOUND-BOARD: ITS FUNCTIONS, MATERIAL, DIMENSIONS, AND ADJUNCTS

In treating of the functions of a sound-board, we cannot claim to be in the region of exact science, and in respect to a large portion of the subject can only say, experience has proved so and so.

The vibrations of strings, apart from resonators of some form, are ineffective to produce really audible sounds. If we can show the reason why this is so, something will be done to make the action of a sound-board intelligible.

While a vibrating string has energy proportioned to the force which sets it in motion, it cannot make that energy available for sound purposes, because its diameter is too small to cause movements of the air large enough to be distinctly audible.

Sound is not a substantial thing; what we call sound is an effect of vibrations of air upon the drums of our ears, conveyed by exquisitely adapted transmitters to the brain.

When anything occurs which puts air into sufficiently vigorous movement, there is set up a series of condensations and rarefactions, which are propagated in all directions, with energy according to that of the original cause.

These are called "sound-waves"; they are not such motions of the air as is wind, but elastic pushes and retreats, the air particles in condensations being closer than normal, while in rarefactions they are more widely separated.

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Each condensed condition is the exact mechanical equivalent of the following rarefaction, and could the latter overtake the former, they would coalesce and mutually neutralize each other.

The opposite sides of a vibrating string are in opposed phases : one is producing a condensation at the same moment of time as the other is producing a rarefaction.

Could these mix, and coalescence take place, then to the extent of such coalescence the energy of that wave would be affected.

This is precisely what does happen ; the air in front of the string, which is being pushed forward as a condensation, slips round to the back, and fills the partial vacuum there formed.

The late Professor Tyndall wrote, crediting, however, the elucidation of the fact to Professor Stokes : "When a string vibrates alone the air slips readily to and fro around so small a body, abolishing the condensations and rarefactions, but this is not accomplished so easily when the vibrating body is of considerable area ; the air cannot then move away in front, nor slip in behind, before it is sensibly condensed or rarefied."

Sir George Airy, writing on the "importance of the connection of musical strings with a sounding-board," says : "The smallness of dimension of a wire, makes it impossible that it can communicate great motion to even the air which it touches. . . . To make it audible, the wire must be connected with an intermediate substance, whose vibrations can produce a stronger effect on the air, and those vibrations (of the sounding-board) must be excited by the vibrations of the wire."

And so, strings of musical instruments, instead of being allowed to waste their force in the futile endeavour to produce audible sound waves unassisted, are induced to spend their energy in moving a sound-board, which in its turn moves large zones of air, with commensurate increase in the loudness of the sound.

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It must, however, be understood that there is no real increase of force; it is only more effectively used.

In mechanics you never get anything for nothing, but are compelled to pay full price for every advantage.

The more completely any resonator fulfils its duties, i.e. the greater the amplification of a sound, the shorter its continuance.

A string set vibrating between absolutely immovable points, would continue its movements for a very long time, but give it a resonator, either a sound-board or an adjusted column of air, and the assistant will also act as a brake, and pull it up in time just proportionate to the degree of amplification.

There is a very beautiful experiment often used to illustrate this. Very large tuning-forks of low frequency are used, with resonance-boxes of capacity adjusted to their frequency. These forks are set in vibration by a stroke of a violin bow. When held in the hand, apart from the resonator, the duration of their comparatively feeble sound is marvellous. Marvellous also is the magnitude of the sound when the fork is used in conjunction with its resonator, but it is very soon ended.

Experiments made by Lord Rayleigh, showed the time loss due to resonation of the sound of such forks as 44 per cent.

The record leaves us to presume that the resonation was at its maximum.

Probably pianoforte sound-boards do not approach to such a maximum but the purpose of the above recitation is to show, that in the pianoforte, which, being a percussion instrument, depends for its "singing power" upon the effect of a single blow upon the strings, the fullest possible resonation should not be aimed at, but only such measure of it as is consistent with reasonable duration of the sounds.

The problem for the violin maker is not quite the same; the strings of bowed instruments are mostly agitated during the whole time the notes are required

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to be audible, and therefore in these instruments resonation might be complete with advantage.

The way in which a sound-board moves, so as to render audible all the complex motions of the strings, and send each fundamental and overtone forth in its due intensity to gratify our ears, has not yet been discovered. We can, however, say we know one thing: its actual movements are not of great amplitude.

And this also seems certain: there must be, for every separate pitch which is thus reproduced and magnified, a corresponding movement.

If the complexity of string movement, proved by experiment to sometimes extend to 37 superposed undulations, surprises us, we become astounded as we think of a structure of wood responding not only to the many components of one note, not only to all those which may be struck together by the hands of a performer, but also to the incalculable number of vibrations awakened, by resonance, between the strings when a performance is in progress with the sustaining pedal depressed. Its capacity in this respect seems to be limitless.

The effective movements must be superficial. There are those who contend that they are molecular, a sort of internal friction.

Probably there is such friction, but this seems certain: the board can only move masses of air by movements of its own surfaces, so if interior movements contribute to the effect, they must in some way be translated into surface motion.

The Material.

Most woods and metals would serve as resonators, with varying degrees of efficiency.

Among the metals, iron, copper, and aluminium have been tried, but only experimentally; the first results seem never to have warranted a continuous departure from the common practice.

Ages of experience have concentrated the choice of

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stringed-instrument makers upon the wood of cone-bearing trees. It is said that the early Italian clavichords, spinets, and harpsichords were bellied with cypress wood.

Some of the coniferous woods seem radically unsuitable, by reason of their great density; for instance, the pitch-pine, which has a specific gravity as high as 0·660.

There is a double peculiarity in the woods of the conifera revealed by the microscope, viz. the absence of the system of variously distended ducts and vessels found in other woods, and the presence, in the cells, of what are known as bordered pits. The ends served in the life of the trees by these characteristic features is not understood, nor is it clear that they contribute to the special resonating value of these woods.

The wood now almost universally used by European pianoforte makers is that of the *Picea excelsa*, the widely grown Norway spruce; sometimes, however, *Abies pectinata*, a very similar wood, indeed scarcely distinguishable, takes its place. In the trade the wood is called "Swiss pine," but it must not be confused with *Pinus Helvetica*. The reason for the name is, the wood of suitable character was for many years cut in the mountainous forests of Switzerland, where the conditions produced tall trees, with trunks very free from knots, and remarkably straight in the grain.

In America a similar wood is yielded by the *Picea alba*.

The Swiss forests have long been denuded of suitable trees and recent supplies have come from the Carpathian ranges.

The annual rings of hard and soft grain are far more regular than in most other woods.

The medullary rays are so fine as to be almost invisible, although the wood is cut on the quarter, but they contribute a good deal to its strength and elasticity.

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Although not containing so large a proportion of resin as some of the other trees of the family, there is a distinctly marked secretion in the hard grains, which as years go on, evaporates and leaves the wood soft and woolly.

It has been suggested that the suitability of this wood for sound-boards arises from the fact that there is a kind of rough average proportion between the amount of the soft wood, that which is formed early in each season, and that which is formed in the later part of each year's growth, the proportion being affirmed to be as two of soft to one of hard.

If this proportion does exist, when reckoned over a very large quantity of material, it certainly is not evident in single boards, or even in the quantity united to form a single belly, and therefore the cause of the superiority of the wood cannot be thus located.

There was one London pianoforte maker who was so sure that in this was to be found the special value of the Swiss pine, that he patented an artificial belly wood, made of layers of very hard and heavy wood, alternated with the very softest and lightest he could procure. The specimens exhibited had the hard wood in about $\frac{1}{16}$ in. and the soft in $\frac{1}{8}$ in. widths. The quantity of glue contained in this compound, with the consequent liability to failure in moist situations, was a sufficient condemnation.

While we are ignorant of the structural reasons which render this wood the most suitable for the purpose, there are three facts in connection with it which probably contribute to, and perhaps jointly supply, the reason.

First, it transmits vibrations lengthwise of its grain with greater rapidity than most other woods, with the same rapidity as does steel, and is only slightly inferior in this respect to glass. It is true that it is not *as a transmitter* that a sound-board is used, but it is easy to see that the more rapidly the effect of the vibration of the strings is distributed over the whole area, the more effective it will be as a resonator. The effect

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over the whole surface should be practically simultaneous.

Second, the wood is exceedingly light, and therefore easily responsive to the minute shocks communicated through the bridges.

Third, it is both very flexible and elastic; the difference in the proper meaning of these terms has been previously noted.

The sum of these qualities, all highly essential, seems to mark out this wood as the fittest to use under present conditions, for there is no other which possesses all of them in so high a degree.

But there is a defect which it shares with all woods; the rate of propagation *across the grain* is very slow, being roughly only one-quarter of that in the direction of the length.

Practical means of overcoming this defect are discussed under the head of "Bars." The defect leaves even Swiss pine at a discount when contrasted with some of the metals.

The rate of propagation is taken in contrast with that through air, which is about 1,125 ft. per second.

Fir wood, however, in the direction of its length will transmit at a rate of 15,218 ft. per second, over thirteen times as rapidly as air.

Iron has the highest rate among the metals, with 16,822 ft. per second.

Against it there is, however, the great comparative weight, but presumably in any serious and continuous trial of iron sound-boards, a commensurate reduction of thickness would be tested.

But the point to be noted is, that while iron has only a small advantage over Swiss pine, when the latter is tested in the direction of its length, there is no question as to its superiority in this particular, when the pine is tested across the grain, for then the rate in the iron stands to that in the wood as 4 : 1.

To make a fair comparison, the *average* rate in the wood must be taken, which then becomes only 9,800 ft.

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length of each bar—is still unattainable except at the cost of a very large reduction of area.

Nearly every maker of overstrung upright pianos either removes a large triangular piece from the bottom treble corner, and from the top bass ditto of the sound-board, or renders those portions ineffective by the use of dumb bars.

The shape of the grand piano limits the sound-board area at the treble end, and in many cases a large triangle is put out of action at the bass corner.

These practices have been induced by experience only, and belong to what Sir George Airy calls our "rude masterings."

The actual area, therefore, is determined by the desired balance of loudness and continuance, and partly by the position of the bridge in relation to the length of the bars.

There is no rule as to the thickness of the sounding-board, or any scientific reason known why any particular thickness should be preferred. A fairly general consent gives a thickness of 9·5 mm. to the treble part, reducing to 6·5 mm. at the bass.

Direction of Grain.

Up till the introduction of overstrung scaling, the usual practice in this country was to place the grain horizontally and the bars at right angles thereto.

If we are to secure the advantage of the much greater rapidity of transmission of vibration, of which the long grain of the wood is capable, reason points to the direction of the grain being parallel to a line drawn through the curves of the long bridge, and to the bars being placed at right angles to this line.

The writer is not aware of any other reason than rapidity of distribution of the effects of the strings' motions which should influence the grain direction. Although it anticipates somewhat the subject of the barring of the sound-board, it seems necessary at

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this place to show how that rapidity is secured over the whole area of the board.

From end to end on a diagonal line, the vibrations received through the bridge, are conveyed with a velocity of over 15,000 ft. per second, and to compensate for the comparative slowness in the other direction, at every few inches a bar offers its help, and, as it were, compels the cross grain to carry them at the same rate.

Thus the radical defect of the wood is compensated for, and practical equality secured.

A complete reversal of the direction of the grain in the board, and therefore of the line of the bars, gives the same results, and some instruments of the highest class are bellied this way.

Bars or Ribs.

One function of these has been already described. They are distributors, conveying (along their grain) vibrations received from the strings through the bridge and board more rapidly than those vibrations could otherwise be carried.

They also serve the very important purpose of enabling the belly to resist the down pressure of the strings. They really are girders, or arches of very small curvature.

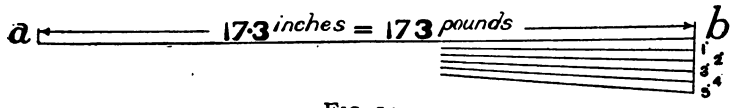

Fig. 14.

It may be useful and interesting here to figure and describe an easy method of calculating the load which these girders have to sustain.

Having ascertained the average tension of the strings, decide upon a length unit, which shall represent each pound of such tension.

Say the tension is 173 lbs., and the unit shall be $\frac{1}{10}$ of an inch.

Draw a straight line, *ab* (Fig. 14).

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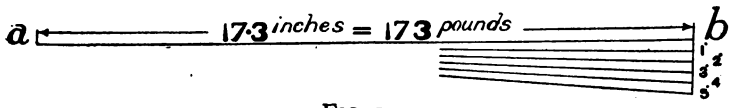

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Draw a straight line, *ab* (Fig. 14).

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From a convenient point under that line draw other lines making angles 1 deg. to 5 deg. with it.

From the point of intersection measure along *ab* 17·3 inches.

As many times as the unit will go into the space between *ab* and any line under it, measured on *b*, is the number of pounds with which a string of the above tension will press, at that angle, upon the bridge.

This, if multiplied by the number of the strings, and the sum divided by 2240, will express the total load in tons.

On the conditions of tension as above, each degree means nearly half a ton.

To oppose to this load an elastic pressure is the task of the bars, considered as girders, and every assistance which can be given to enable them to bear it, without destruction of their elasticity, should be granted.

The old pianoforte makers were grossly ignorant and careless in this matter. They did indeed curve the faces of the bars to about the same degree as is still commonly used, somewhere in the neighbourhood of a 60-ft. radius.

They then placed their planed-up board upon a flat table, and glued down the bars, bending them so that the curve which had been made on the front was forced to the back. The consequence was that when the pressure was released, the bars endeavoured to resume their former curvature, and succeeded in part, but only so far as the board could be made to follow.

This practice put the board in a condition of tension across the grain, and in tension it remained during its whole life.

If shrinkage took place afterwards, and it often did, the effect on the joints was serious, and additionally the strain in the board was always acting, along with the down bearing and other stresses, to depress the bars.

For some reason, never stated, it was regarded

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as desirable that the surface of the board should be in tension.

The very opposite is the case, and modern practice all over the world, aims to put the board itself into a state of compression, so that it is constantly acting to assist the bars to do their duty.

The writer's own formula is: Arch the bars to about the usual curvature, keep the board warm at, say, 100° to 120° F. for a few hours to shrink it.

Place it on a frame or board hollowed out a trace deeper than the curve of the bars, and while the board is hot glue the bars down.

When the pressure is released, the rounding will be rather greater than the original curvature of the bars, and the board in a condition of considerable compression, which it will retain and which will increase a little.

The backs of the bars which by this process become a little hollow in the length, are afterwards planed straight.

The whole structure thus becomes a highly elastic spring.

There is no rule as to the number and dimensions of the bars, and yet there is an unconscious approximation to agreement as to the total sectional mass of them.

Examination of the barring used by high-class makers, shows this mass to be equal to about 10 sq. in., the width and thickness of each bar being measured in the middle of its length.

As burden-bearers they are subject to the laws which apply to girders.

One of these is that additions to width, increase the strength just as the width increases, but additions to depth, increase the strength as the square of the depth.

So that, if a bar of 1 in. square is equal to a certain load, a bar of 2 in. × 1 in. *on the flat* is equal to twice the load, but on the edge it will carry four times what the 1 in. × 1 in. bar could endure.

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In modern construction, space will not permit great depth, but it is inadvisable to make bars, in the middle part of the instrument, wider than they are deep.

The best present usage makes them nearly 1 in. square in the middle part, with a slight excess in the depth, and with a gradual reduction in the width toward the bass and treble ends of the instrument, but with a rather greater reduction in the depth. So that the centre bars are rather deeper than they are wide, and the end ones rather wider than they are deep.

Some makers scallop the ends more deeply than others; there is no rule, and the matter seems not to be of great importance.

It is not wise to make them so thin as that if exposed to damp it can easily penetrate and soften the glue; I regard about $\frac{1}{8}$ in. to $\frac{3}{16}$ in. as a fairly safe thickness.

Naturally one would prefer that the material of the bars should be belly wood, but that is now so expensive that most makers are using ordinary spruce of best quality, which seems to give equally good results.

A few American pianos are (except at the treble part) ribbed with pine; careful experiments seem not to show that this material gives better results than spruce, and it is now so scarce as to be (in this country) only procurable at most extravagant prices.

A proposal was made some years since to substitute for bars a double thickness of belly with the grain of the two layers at right angles. Considered from the point of view of rapidity of distribution only, the idea was a good one, but the resisting power in proportion to weight was very small, and there did not seem to be any tone superiority in the samples shown to justify an expensive departure from established usage.

The edges of bellies should be rigidly fixed; the modern construction of grand pianos provides in the

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dense continuous rim and hardwood belly rail, the best fixing possible.

The fixing in upright pianos cannot be so solid, but every endeavour should be made to prevent what (for convenience in expression) we may call leakage. The undulations as they arrive at the edges should recoil with a minimum of loss.

The Bridges.

The function of the bridges is to convey to the sound-board the effect of the vibrations of the strings, the transverse motions of which are manifestly felt at the ends, as shortenings and elongations, the speed of these being as the frequency. Added to the main effect of the fundamental, there are also the effects of all the overtones, and the complexity of the motion passes one's ability to conceive.

Apart from a few experiments mentioned in the chapter on "Bearings," the connection of strings with bridges has, from the beginning, been secured by the same means as now used, viz. by a down bearing, and by having the direct course diverted by two rows of pins, causing an angle to be made proportioned to the diameter of the pins and the distance apart of the rows.

The overhanging angle also, that which the pins make with the top of the bridge, much assists to keep the strings in close contact.

Of necessity, bridges are either made of, or faced with, quartered beech; no other wood can endure the strain which the side pull of the strings exerts.

As regards the direction of the grain of the bridges, the same law holds as that which determines the direction of the grain of the belly.

Even were it not economical and convenient to make the bridges with the grain lengthwise, yet to secure the utmost rapidity of action it would be necessary.

As, however, the grain does not follow the curve

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required, it is of advantage in every way that the long bridge should be made of pieces cut as nearly as possible with the grain, and lap-jointed together at the places where the bars of the iron frame cause the scale to be divided.

The height of the bridges has perforce been much increased since the introduction of iron frame construction.

For very many years, both long and bass bridges were cut out of 1 in. beech, and were often finished under $\frac{7}{8}$ in. in height, but of late the long bridge, by general tacit consent, stands $1\frac{5}{16}$ in. to $1\frac{1}{2}$ in. above the belly, and the bass bridge from $\frac{3}{4}$ in. to over $\frac{7}{8}$ in. higher still.

No definite proportion between the tension of the strings and the height of the bridge has been discovered. It would not be surprising were it to be found that a further increase in height was of advantage.

Beech is among the slowest of the woods as a conveyer of vibration, as might be supposed from its weight and inelasticity, but its strength dictates its use.

It is not, however, necessary that it be used for the full height: if there be enough to hold the pins it is sufficient; and some makers have taken advantage of this, and made the long bridge of spruce or maple for more than half its height.

The use of spruce, if it also be jointed as above, certainly has a theoretical advantage equal to its higher rate of transmission.

There is a method of making bridges used by some of the highest-class makers which seems to be founded on a recognition of theoretical limitations of the solid bridge; they bend them of several layers, with the joints rectangular to the face of the board, and by this means secure the desired continuity of the grain. There has to be a layer of solid beech upon the top, but usually the pins, being driven right through this cap, make good connection with the

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bent portion. The wood mostly used for the bending is maple in $\frac{3}{16}$ in. layers, and in widths sufficient for several bridges.

The amount of glue included is objectionable, and there is some risk of joints opening in very moist climates; the cost also is greater.

Having used this method somewhat largely, I think it has advantages, and I have never known the joints to fail.

I have sometimes also used alternate layers of Swiss pine, so as to gain the help of its very rapid rate of transmission.

The division of the scale at the breaks for the bars causes a widening of the bridge at these places.

This is objectionable, as it renders it less able to perform its rocking action at these parts; and it is advisable to either bevel or rebate away the projections on the underside, so as to provide a continuous curve of nearly equal width at the line of attachment to the sound-board.

At these places also, some cutting away of the depth of the bridge is required in upright pianos, so as to clear the frame bars.

This cutting should be as shallow as possible, and made up at the back in one of the ways advised in the chapter on "Scale Drawing."

The reason for this is, that if the bridge is quite divided, or even deeply cut, there is a failure of conveyance of vibration, and short, shocky tone in adjacent notes results.

Piano makers used often to attribute this to the nearness of the bars themselves.

The bridges are better glued on after the bars, upon a bed curved in both directions, made of rails which permit the bars to lie between them, but, whether applied first or last, the underside should be planed away (upon a convex fitment) to the general curve, so as to assist in the preservation of it.

The height of the bass bridge, in overstrung construction, is determined by the need for the lower

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strings upon it to clear the vibrations of those beneath, and the height varies with the length, on which subject see the chapter on "Contraction Drawing."

As in the tenor portion, so in this, it is not possible that the bridge should stand in a position central to the length of the bars.

It is vital to make bass strings as long as they can be consistently with placing the bridge upon a part of the belly which can respond to the action of the strings; and so the expedient of a suspended bass bridge has come into fairly general use. Its value is far in excess of its small extra cost.

The depth of the suspension from the point of attachment to the belly is often dependent upon the room which can be given without dangerously narrowing the "belt" of the iron frame, where it joins the bar which crosses the tenor strings.

The writer prefers that the suspension should not be deeper, at the treble end of the bass section, than half the width of the bridge itself, increasing to, say, not more than 3¼ in. at the lowest note, or as much of this as the other dimensions will permit.

One thing should not be omitted, viz. to make the slip which attaches the suspension to the belly, long enough to reach to at least one bar on each side beyond those which lie under the bridge itself; if even more can be grasped, the better.

The Varnish.

It has already been pointed out that the natural resin of the wood slowly evaporates, to its serious damage as a resonator, and so it is highly desirable that the surface pores should be sealed with some matter which will retard this, and yet not of itself be of detriment to the resonant qualities.

The writer does not believe that the varnish contributes to resonance, but only retards decay and improves appearance.

In Europe, a solution in alcohol of sandarac and

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other softer and less brittle gums is almost exclusively used, several coats being laid on.

In America, a solution of celluloid, finished with a final coat of a quick-setting oil varnish, seems to be favoured.

Whatever be the composition of the varnish, it is important that it should seal the grain, be sufficiently elastic not to crack, and that its solvent be a very rapid evaporator, so that the period of drying be short.

Pianoforte makers are rather careless about their varnishes and polishes, all of which have alcohol for solvent; they forget its intense affinity for water, and expose it to the air a good deal, not thinking that, although its quantity may not be very much reduced, a detrimental action is going on, the percentage of alcohol is being reduced, and its place taken by water.

I think that often the cracking of varnish on sound-boards is caused by this deterioration. The milky effect which appears when a sound-board is varnished in a cold, damp place seems due to the assimilation of water from the air, with a consequent dropping of the gums, much to the detriment of the surface when dry.

When first produced at the distilleries the "Industrial Spirit," which is the solvent used, is supposed to be 61° to 64° over proof. Proof spirit contains only 57 per cent (by volume) of alcohol, the remainder being water, and this strength is insufficient for a varnish solvent.

Industrial spirit 63° over proof means a spirit of about 92½ per cent, of which 5 per cent is wood naphtha, and the remainder water.

The naphtha as a solvent for varnish differs little from the alcohol.

The percentage of water increases with every exposure.

Experiments have shown the penetration of the varnish to be very slight indeed, and, except through the end grain, not to be detected.

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Seeing it is declared credibly that the slow-drying oil varnish used by violin makers sometimes completely penetrates the thickness of the maple and pine of which these instruments are made, and shows inside, the difference must be attributed to the rapid drying of the alcohol varnish.

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CHAPTER VII

BEARINGS, ETC.

In a previous chapter we have discussed the down pressure exerted by the strings upon the belly bridges, and have shown a method of calculating the amount of the same (see Chapter VI and Fig. 14).

That method is applicable to all cases in which cords in tension make angles in this way.

Other ways than the usual one, of securing close cohesion between the strings and belly bridges have been tried, the object being to relieve the sound-board of the downward and twisting strains to which it is subject, either by a system of alternate up and down pressures, or by locating the strains between the limits of triple studs.

These ideas have been patented many times, but have never been extensively used.

It does not seem that the usual strains, if moderate, are detrimental.

The down pressure, although often excessive, was not the sole cause of the frequent failure of sound-boards in olden times.

The causes should rather have been looked for in the way the board was made (see "Sound-boards"), and in the bending of the bracings, and consequent pressure on the edges of the board, exercised in a line in which it was most effective for mischief.

These causes no longer exist, and the writer thinks the established plan will probably not be superseded.

The bearings which have now to be considered are those made at and above the wrest-plank bridge.

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Studs.

This form of bearing was first used in grand pianos, and the pattern of the grand stud has not really varied from the beginning. Its introduction was due to the serious difficulty found in olden time, because the blows of the hammers, delivered upon the underside of the strings, drove them away from the wooden wrest-plank bridge then used.

The stud, in which the strings bear against the upper side of the holes, completely remedied this defect, and is still (by some makers) used throughout grand pianos, although most have adopted, for the upper half of the instrument, the heavy cast-in bearing bar ; indeed, sometimes this form of bearing is used in the lower portion also, and most effectively.

In the top octave of grand pianos it is somewhat difficult to place studs of the ordinary pattern, because the room required for the hammers does not really allow sufficient space for the tapped holes to receive the studs, even though they be made to overhang considerably.

A special stud was used for awhile for this part, which was ingenious and effective. It was in principle an upright double-bearing stud reversed. This allowed the centre to be placed further from the wrest-plank edge, and gave also a better clearance for the treble hammers.

Still, in view of the satisfactory results attained by the use of the cast-in bearing bar, there is no present inducement to design grand pianos with stud bearings in the upper part.

The original pattern of stud is not applicable to the upright piano, for the very same reason which makes it so efficient in the horizontal instrument.

Various plans were tried to adapt same, by which the stud was joined to another bearing, placed in connection with it, sometimes associated in a continuous bridge, but such forms were never fully satisfactory,

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mostly due to the attachment to the face of a wooden wrest-plank not being as secure as was necessary.

They are all now extinct, having been completely outclassed by the double-bearing separate studs, which form on the whole, perhaps, the most effective upper bearing yet designed, when tightly screwed into a solid iron base.

There are no features of disadvantage except expensiveness, which naturally causes this bearing to be regarded with some disfavour.

Its advantages are, it automatically spaces the strings and keeps them in position. It permits, if necessary, the part of the string between it and the wrest pin to follow a line diverging from that of the speaking length. It provides a properly adjusted down pressure upon its lower ridge, and that ridge itself is machined to unfailing regularity of radius, and, moreover, it can be so set that its bridge is at a right angle to the centre line of the note.

The mere provision of an individual bearing for each note does not seem to have any special value.

The fact of studs being made of brass prevents a little difficulty which sometimes develops with iron bridges in damp situations. Rust takes place at the point of contact with the strings and renders them difficult to move with the delicacy needed for tuning.

If the softer metal used in studs has any effect upon tone, this effect should also occur when the brass-wire bearing is used.

The other forms of bearing now in common use, are the iron bridge and the same with a wire apex, both requiring a pressure bar.

The latter form shares one of the advantages of the stud, viz. a regular curvature at the place of resting of the string, and the absence of this is the only way in which the iron bridge is much inferior. The finishing of such bridges is a matter of hand filing, done under most difficult conditions, and the results are often far from perfect.

The only fault which the writer can allege against

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the wire bearing is, that he has known the bedding of the wire in its groove to be imperfect so that jarring noises have been caused. This is due to the casting of the groove being irregular.

To reduce this difficulty the wires should be soft, and not of large diameter, so that they may easily adjust themselves to small irregularities.

Care should be taken to ensure that the pressure on the bridge should be (while not excessive) sufficient to prevent the motions of the strings being continued beyond it.

The purest tone and longest continuance cannot otherwise be secured.

The strings must not, however, be held so tightly as to prevent them slipping easily as the tension is altered by the tuner.

A safe pressure, securing both desiderata, is obtained when, crossing the bridge, the strings make an angle of between 15 deg. and 20 deg.

The attempt to obtain a sufficient pressure by one backward angle causes an immense forward pull on the top edge of the wrest plank.

Fig. 15 shows the effect of an angle of 15 deg., carried direct from the bridge to the wrest pin, and also of the same angle produced by the intervention of a pressure bar, or of some other means of pulling down the string, at an intermediate place.

In the first position the string is pressing upon the bridge with a force of about 45 lbs., and the same force is being exerted as a forward pull upon the upper part of the wrest plank.

The total effect is easily calculated upon the assumption of all the 88 notes having an equal effect, which will not be very far from the truth.

$45 \times 3 = 135$ per note, $135 \times 88 = 11{,}880$ lbs. $\div 2240 = 5\frac{1}{4}$ tons, engaged in the endeavour to pull forward the top of the wrest plank and frame; whereas by the intervention of a pressure bar, the same pressure on the bridge can be maintained, and yet the forward strain almost neutralized.

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The complete elimination of this strain would involve a rearrangement of the usual levels such as would be somewhat troublesome in manufacture.

However, it is quite easy to reduce the angle made by the strings between the pressure bar and the wrest pin to about 2½ deg., which reduces the forward pull to 5½ lbs. per string, an aggregate of 1,452 lbs., considerably less than three-quarters of a ton.

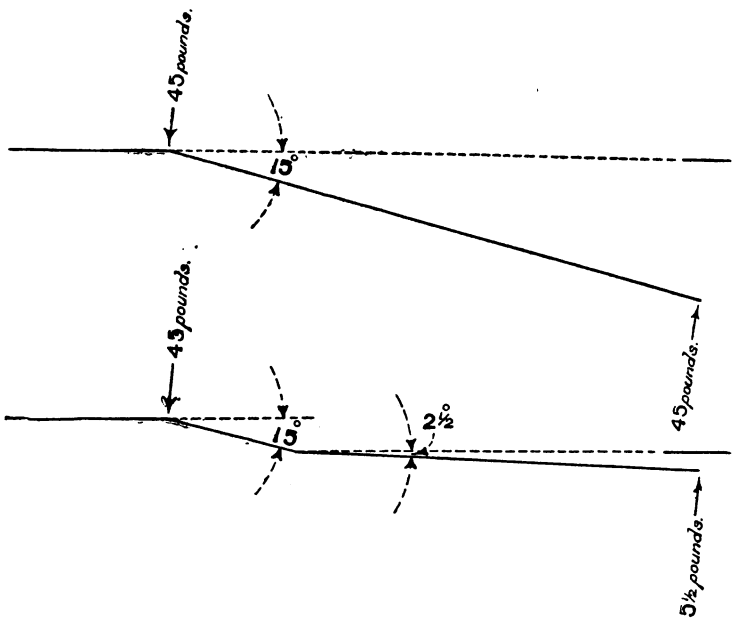

FIG. 15.

If it be desired, to reduce the strain caused by the backward angle in the bass part, it can be accomplished in the way shown in Fig. 11.

The full downward pressure of 45 lbs. upon the bridge can thus be given and the forward pull on the top of the wrest plank reduced to a quite trifling amount.

Pressure bars should be fairly stiff; the common practice of making them of less than half round section is dictated by motives of economy.

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Where it can be afforded, it is better that they should be of even thicker section than half round, and in pianos with a higher tension than 150 lbs. per string, there should be a screw to each two notes.

The use of a third bearing placed between the pressure bar and the wrest pins is quite unnecessary.

The adhesion due to pressure of the bearing points is considerable, and often embarrasses the tuner; a third bearing increases the difficulty.

A piece of soft felt or cloth of the right thickness placed beneath the wrest pins, and the pressure bar screwed down until the strings just touch the cushion, will silence vibration and not add to the adhesion.

It is wise to lubricate the bearings. A stroke of paraffin wax along the top of an iron bridge—or of a wire ditto, or on the bearing part of upright studs, as well as on the round of a pressure bar—assists much to reduce the friction.

The holes in studs cannot easily be lubricated.

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CHAPTER VIII

KEYS AND ACTIONS

ALTHOUGH not originally covered with ivory, the natural keys have been for so many years of this material, that doubtless no other would have been sought but for its increasing scarcity and consequent high price, and even now it holds the field against all competitors as the proper material in instruments of high value.

It looks, however, as though the supplies could not long hold out against the enormous comparative demand, although the use of other materials in the manufacture of articles for which it was once almost exclusively used, has, up till the present, helped to eke out the reducing quantity brought to Europe.

The thickness now used on keys is very much less than that of former times, and various systems of bleaching have made it possible for the selection of suitable material to be less wasteful.

It looks, however, as though the time could not be far distant when pianoforte makers will need to depend chiefly on other substances.

Various substitutes have been proposed, but the only ones which, so far, have been able to command extensive use are "celluloid" and "galalith."

The names are significant of their origin. Celluloid is made largely of "nitro-cellulose" mixed with camphor and other materials.

Galalith is made from the casein of milk and seems to be of the nature of cheese, doubtless hardened and toughened by the addition of other materials.

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The name, freely translated into English (for it is a compound of Greek words) means simply "milk stone."

When first introduced, both these materials left much to be desired. The adhesion of celluloid to the wood of the key was rather uncertain; this, however, has been remedied, and also means found for finishing it with a higher polish. Its colour now is excellent, and seems even more durable than that of most ivory. It has the great commendation of being low in price, and certainly a good set of celluloid keys is to be preferred to ivory of the lowest grade.

Its chief disadvantage is its extreme inflammability, which at first seemed an element of danger, both in the factory and in the home, but this fear has not been justified; however, reasonable care should always be taken.

Players used to complain of the feel of the celluloid keys, but this does not now seem to be an objection to its use.

The early difficulties with galalith, called in France "elfinite," arose from its great sensitiveness to hygrometric changes. It would swell and shrink so much that it would sometimes detach itself from the wood, or, if it could not do so, would, in shrinking, fracture across, often at the part where the tail of the key joins the head. This tendency has been combated with such success that the galalith key has become a favourite in some countries.

One great advantage which celluloid has over both ivory and galalith is, that it can be shaped right round the key, tail, head, and front, in one piece.

This has no value in moderate climates, but in those called "extreme" it has. When ivory keys have to be screwed, or pinned, as a safeguard against separation, due to the effect of heat and moisture, the appearance is unpleasant, but with all-round celluloid, pins can be placed in invisible positions, at the end of the tail and at the bottom edge of the front.

The wood originally used in this country for keys

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was that of the lime-tree or linden. While plentiful, so that only the straightest grown logs would be chosen, and those cleft, not sawn, into boards, perhaps no wood could surpass it for the purpose.

But as it grew scarce, and the wasteful way of conversion by cleavage was given up, the direction of the grain could no longer be controlled, and great trouble was caused by warping. It has now practically gone out of use, and two woods have taken its place.

Perhaps the best of the two is the Swiss pine, cut the opposite way to that proper for bellies, the other is bass wood, an American timber, of texture and odour very similar to lime-tree, but either naturally, or because of care in selection and conversion, minus the fault above mentioned.

The only defect which can be alleged against Swiss pine, as a key wood, is that its softness makes the lower part of the balance-pin holes liable to damage by accident or wear.

This can be much modified by an application of collodion, which hardens and waterproofs the wood around the hole, when a little is placed therein; it must be used sparingly, and not allowed to get through to the cloth of the bushed mortice above. Methylated collodion is cheap.

Viewing the key as a lever, intended to convey, without any avoidable loss, the force put forth by the fingers of the performer, flexibility would obviously be a serious fault, and therefore any appreciable spring must be prevented.

The board should not be thinner than 1 in., and if the keys are long (as in grand pianos) $1\frac{1}{16}$ in. is better.

This same consideration should rule in the selection of the cloth for the circles, upon the balance pins, upon which the keys rock; and this is true of all cloth, felt, and leather, which have to serve as transmitting force between the performer's hands and the blows of the hammers upon the strings; they should be, while soft enough to be silent in action, as firm as possible, so as to avoid loss of motion, the amount of which is

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sometimes very large, and noticed principally in heavy playing.

The cloth-bushed mortice is now universal, and the oval form of front key pin almost so. This is much misused in regulating; it is treated as though its oval form was intended to compensate for careless easing of the mortices.

Undoubtedly, by turning the oval pin upon its centre, and thereby increasing its effective diameter, it does act as a compensator for the effect of wear, and it is intended that it shall do so, but when an instrument leaves the hands of the regulator, the longer axis of the pins should be accurately parallel to the line of the keys, the primary value of this form of pin being that it presents a wider face to the side of the mortice and reduces the rate of wear accordingly.

The usual methods of easing bushed mortices are very uncertain and wasteful of time. By the use of a warm, almost hot, metal broach, adjusted to the correct thickness, the work may be done in very much shorter time than that otherwise required, and with far more regular and permanent results.

The writer's own way of using this method is for the broach to be a horizontal fixture, heated by the flame of a spirit lamp, the heat of the effective part being adjusted by the distance of the flame from it, and the keys are then applied to it, several being held in the hands at a time.

The taper of the broach must be very slight, and there must be a stop to prevent its going further than the required distance.

When one has had a little practice with this mode of easing it can be done with such regularity as to eliminate the need for the trial of individual mortices, and moreover, the results are much more permanent, not being dependent upon mere compression with pliers or wedge.

While upon the subject of key easing, a word may be said in defence of an old practice which seems

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to be falling into disuse, viz. the broaching *on the skew* of the round hole for the balance pin.

If the file or broach is applied to this hole at a right angle to the length of the key, the fit may be made quite free when the key is resting on the balance-punch-cloth, so free, indeed, that it may tend to rise from its seat when heavily struck, but at the same time be very difficult to remove by lifting the front.

If, however, the broach is used at an angle slightly greater than that made by the balance pin itself (when the key is lifted off by raising the front), removal is made quite easy, and yet, when the key is depressed in playing, the fit of the hole can be amply tight enough.

The practice seems to be growing, particularly on the Continent, of making these holes so tight as to render it very difficult to "lay" the keys, which, however, if properly eased, should fall to the position of rest by their own weight.

The loading of keys for modern actions is only necessary as adjusting the weight of the touch, as they are not now required to return independently of the action; indeed, in many cases they have to be given a tendency to fall to the front.

The weight of touch now mostly preferred is from about 3 oz. in the lower bass portion of the compass, reducing to about 2 oz. at the higher treble, the weight to just carry the hammers to the strings. This usually means that in upright pianos some back loading is required at least at the treble end.

In most grands, however, because of the weight of the action and hammers, due to their horizontal position, it is necessary to load the front of the keys considerably in the bass and middle portions, with sometimes a little loading at the back at the treble, beyond the end of the dampers.

The front loading can be (and often is) avoided, with no corresponding disadvantage, by using springs of graduated strength to carry part of the weight of the action, applied to the notes from No. 1 to about No. 50, where usually the need ceases.

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To load the keys is perhaps a trifle less expensive. I have sometimes also counteracted an excessively heavy fall of grand hammers by a similar device, of springs with cord loops inserted in a selected position in the hammer shank, the other ends of the springs being in a rail at the end of the shank flanges; this can only be done subject to the room between the action and the underside of the wrest plank being sufficient.

It is not often that the fulcrum or balance point of a key has to be calculated merely from the vertical rise of the lever of the action.

Every action manufacturer knows what proportions of balance and back-length are required for each type of action he makes, and will willingly supply the information. The proportions are a ratio compounded of the vertical rise of the action lever, plus whatever is lost by forward motion at the top of the pilot (if one is used) to the depth of the touch, which it is customary now to make 10 mm., when tested with a weight sufficient to very slightly compress the front baize.

The effective depth, however (that required to carry the hammer through its course), should not, in upright pianos, be more than 9 mm., the remainder being needed for ensuring the escapement and locking the check.

Although the same, or even a larger, allowance is often made in grand pianos, it is unnecessary, and produces a jerky feeling as the fly escapes from under the roller, and so, for these, depth of touch and lift of action should correspond.

Supposing the action levers in upright pianos just to ride on the top of the keys (or prolonges to be used which scarcely waste any motion), it is a fairly safe rule to ascertain the amount of the vertical motion of the lever (measured at the centre of the foot or drop) required to propel the hammer through a path of 5 cm., and fix that as the proportion which the lift of the back of the key has to bear to the depth of the

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touch, so that were the back lift 5·5 mm., the respective lengths, measured from the fulcrum, would be as 5·5 : 9. But for every increase in the height at which the action levers stand above the keys, if that space is filled by a pilot or block upon the key, a very small corresponding increase must be made in the lift proportion on account of the loss by circular motion.

A far more frequent problem is, that in consequence of a change in case dimensions, a fulcrum point for a new length of key must be found of the same proportion as one already in use.

There are several simple graphic ways of doing this.

Upon a board or sufficiently large sheet of paper, rule a straight line near one edge: this represents the front of the key; then on a perpendicular at one end mark the lengths of the balance and lift point respectively.

On a perpendicular at the other end mark just half these quantities, and unite by two other lines.

Having ascertained the new length required, measured from front to lift point, find (if the new key is shorter) the place where, on a third perpendicular, the front and lift lines coincide with the required new length, and the place of the fulcrum can be marked from the middle line. If the new key is longer, divide the length by two, find the fulcrum as before, and double both lengths.

Another way, requiring a little more care, is figured and described in every elementary treatise on geometry.

Put the new length required from front to lift upon a line *ab* (Fig. 16).

From *a* draw another line *ac*, making any convenient angle, and on this line mark the lengths of balance and lift *de*, measured from *a*.

Unite *e* and *b*, and then precisely parallel to *eb* draw a line down from *d*.

Where this line cuts *ab* is the point which defines the respective lengths for the new key.

A key can be divided in proportion by laying down a line of the length required, measured from front to

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lift ,and then marking under the front, 9 mm. for depth of touch, and above the lift point, the rise needed there. A line uniting these points will cut the first line in the correct proportions, but on account of the acuteness of the angles it is difficult to decide precisely where the crossing is. If, however, both the quantities are multiplied by, say, four or five, the angles become sufficiently obtuse for the crossing to be found fairly accurately.

An arithmetical way of adjusting a new length to old proportions is, add together the known proportions thus :—

Suppose they are as 9 : 5·5, 9 + 5·5 = 14·5. Divide

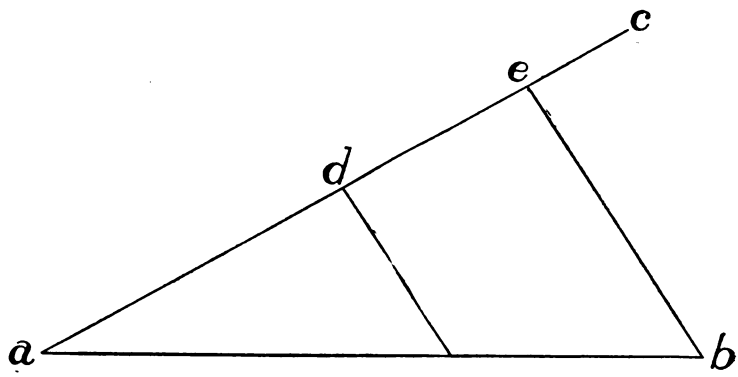

FIG. 16.

the new key length, say, 38 cm., thus: 38 ÷ 14·5 = 2·62. This now becomes a multiplier, thus: 9 × 2·62 = 23·6 cm. 5·5 × 2·62 = 14·4 cm., and the respective lengths from front to balance point, and from that to place of lift, are decided.

To prove correctness, add the quantities thus: 23·6 + 14·4 = 38·0.

There is an irritating defect in keyboards which loudly calls for improvement, which could easily be made.

The spaces between the sharps in the sections F to B are often so narrow that a performer with rather thick fingers cannot play on the tails of G and A.

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The space between C♯ and D♯ is naturally wider than the others, because C to E, which usually measures 70·7 mm., is divided into five, giving about 14·1 mm. to each division, whereas the group F to B, measuring about 94·35 mm., is divided into seven, giving only 13·48 mm. to each. It seems unfortunately to happen that when there are errors of marking out or cutting, the narrow tails are made still narrower.

The difficulty is often increased by the extreme width of the ebony sharps, particularly at their lower part, which sometimes measures as much as 12 mm.

There is no need for them to be wider than 10·8 mm. at the bottom, tapering to 9·8 mm. at the top. These are actual dimensions in use. Were this made the standard, and were the octave C to B inclusive made to measure 165·5 mm., divided thus: C to E 71 mm., F to B 94·5 mm., there would be sufficient room in all the spaces.

It sometimes occurs that sharps are made so low that when depressed they are level with, or even below, the adjacent naturals.

While this can be remedied by raising the clothing, both at the balance and the front, the cure often brings other evils, among them the making visible the stained wood under the ebony. The defect should be prevented by always making the sharps sufficiently high.

The action lever centre should be so positioned that when the hammer is at rest, the front of the lever is as much below the horizontal line, as it rises above it when the key is depressed. The depth of the foot or drop on the lever must be such that it works with the top of the pilot, or the block, as the case may be, without friction. To the extent to which the one comes forward, due to circular motion, the other must follow.

To determine the relative dimensions, draw a line from the lever centre to the underside of the key at the point on which it rocks.

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The depth of the foot on the lever, and the height of the pilot, are just where a vertical line through the centre of both cuts the above slanting line, both lever and key being in the horizontal position which represents one-half their motion. To prove correctness, draw arcs from the two centres of motion cutting this point, and they will be found to run together with the least possible amount of friction (see Fig. 17).

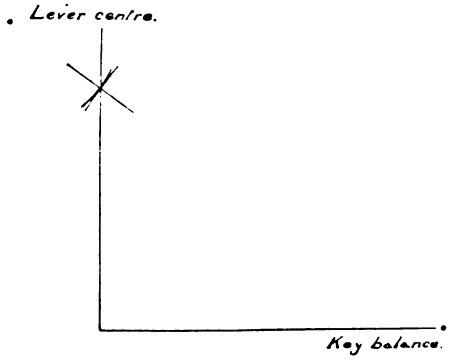

FIG. 17.

There is an easy arithmetical way of making this division.

The height of the pilot measured from the *underside* of the key, and the depth of the foot on the lever measured from the horizontal of the lever centre, are to each other as are the radii of the two circular motions, which on the diagram are as 14·45 : 3·85 cm.

Add these numbers together : 14·45 + 3·85 = 18·3.

Divide the height from underside of key to horizontal of lever centre thus: 12·92 ÷ 18·3 = ·706.

This now becomes a multiplier : 14·45 × ·706 = 10·20 cm. 3·85 × ·706 = 2·72 cm.

These numbers united = 12·92.

If prolonges are used, the same equality of motion is secured by adjusting the height of the back centres of the prolonge levers.

If one end is centred to the key or to the lever, the other only, has to be adjusted.

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It has become a rule to proportion the parts of French actions so that they require that the length of the hammer shall be 13 cm. measured from the centre of the "butt" to a line squared from the shank to the nose of the head.

The fact is often overlooked that this line does not pass through the middle of the head, but sensibly below it at the back, because the heads make a downward angle usually of about 3 deg.

The rule for the blow, i.e. the length of the travel of the hammer, is intended to be 5 cm., which is very close on 2 in.

This is measured in a horizontal line, and therefore is somewhat less than the actual movement, which is curved, being an arc of a circle of about 13·9 cm. radius.

The angle to be made by the hammer-shank with the vertical varies with the action.

One with returning springs does not need so much overhang as does one which depends on gravity alone for the recoil of the hammers, but the usual minimum is 4·5 mm.; measured on the 13 cm. length of hammer, this represents an angle of 2 deg. In testing to determine what is sufficient, it is needful to see that the instrument itself is vertical. I have known a recoil angle to be judged insufficient when, for working convenience, the instrument has been leaning backwards.

In grand pianos, the gravity of the hammers is more than sufficient for the purpose of recoil, and it is convenient for several reasons to allow them to overpass the horizontal position by about 4 or 5 mm., the principal one being that more room is thus provided under the wrest plank to clear the action as it is drawn out and replaced.

The subject of recoil involves a great deal more than the mere fall of the hammer into check.

Whenever motion is reversed by impact, there is a period of time during which the moving object is in contact with that from which it rebounds, and the

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length of the stop is affected by the elasticity of both.

In respect to the recoil of hammers from strings, the elasticity of the shank is of prime importance, for the contact will endure until the shank has regained the position from which the blow has bent it.

Therefore we need for shanks, a wood of small flexibility, but with a high degree of elasticity: the less it bends the better, but what it does bend, should be recovered in the shortest possible time, for while it remains in contact with the strings a hammer is acting as a damper, and tending to destroy the effect of its own work. Additionally, the bending of the shank induces a stroking action of the head upon the strings. The amount of this is very obvious in the top notes of old pianos, with pinned wrest-plank bridges; the last few hammers are often deeply cut by the pins, from which (except for the bowing of the shanks) they are sensibly distant.

It is not suggested that the bowing action is as great in pianos made upon modern lines, but in some measure the effect is bound to be produced.

This undesirable movement is reduced to some extent by making all the strings except those in the bass section to overhang sensibly.

This overhang is secured by placing the frame, so that the covered strings are vertical and the others inclined. The inclination, taken along with that of the hammer head, operates to limit the bending of the shank. This matter is thus fully argued because there is abroad a thought that flexibility in shanks is a feature to be desired.

The wood now mostly used is maple, and except for a liability to warp, it serves admirably.

The writer, however, prefers hickory, which has every virtue which can be claimed for maple in a higher degree.

That the hammer shall deliver its blow without side motion is important. Such action has a very obvious effect on the tone of a note, even from the

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beginning, and grows more distinct as the felt wears. If the marks due to wear are examined in an old instrument, hammers which "slew" can be easily identified by the width of the cuts.

The cause is sometimes in the centres, and in such cases the defect can be cured by packing the flanges and "casting" the hammers to follow. When, however, it is due to twist in the grain of a shank, nothing can be done but to extract, and replace with a new one.

It is important that hammer-butt centres should be very steady; sometimes in the endeavour to secure this they are made *too* tight.

This can be remedied by slightly wetting the flanges with water close to the bushing. The wood is thus swollen, and in its swelling compresses the cloth, and when the moisture dries out, the wood shrinks and the effect is secured. Of course, the quantity of water used must be very small; it should be applied to the outside edges of the flanges with a tapered stick.

The position of underdampers is fixed by the striking-place of the hammers. As the striking-place is the place of the maximum motion of the strings, it would probably also be the most effective place for the dampers, but for various reasons its use is impracticable, even in grand pianos.

However, the nearer the top of the damper felt can be to this place the better.

The longer the heads can be, the more effective they are, but, unfortunately, the position of the centres of the damper arms will not permit the use of extremely long heads; they cannot be removed at their bottom ends far enough from the bass strings to clear their very ample vibrations.

The old overdamper, while it sometimes failed to silence the fundamental immediately, was often more effective as regards the overtones than is that which is placed under the hammer, even when the modern forms of felting, "clip" and "wedge," are used; but there can be no question of the superior

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effectiveness of the underdamper upon the fundamental. Pianos have been made with both forms of dampers in the bass section, the upper set being carried on a short rail. This, of course, much increases the weight of the load to be moved by the keys in this section.

The application of "fly" dampers to the single strings is not uncommon, and is quite effective, although the upper pad is very small and the pressure also slight, but the minutest touch is sufficient.

The objections to these dampers are, a liability to accidental derangement when the action is handled, and a slight additional strain upon the centres of the damper arms caused by somewhat violent vibration, which vibration can be plainly felt on the keys.

The latter defect can be much reduced by placing the damper check-rail in fairly close contact with the damper arm wire. Fly dampers are also sometimes necessary on one or two notes on the treble side of the crossing where the underdamper heads cannot be of full length.

A very effective supplementary damper designed by the writer was in use for many years. It was applied to the single strings only, and was carried on a short rail which was attached to the wrest plank by two small bolts.

The overtones were effectively silenced without the corresponding defects of fly or overdampers.

The action was automatic; when the underdamper moved, the upper one became free to move by the action of its own fine spring.

There was no increase of weight in the touch nor in the strain on the centres of the underdamper arms.

It was more expensive than an equal number of fly dampers.

It is a mistake to make, as is sometimes done, a stiff connection between the damper buttons and heads, in the bass section; the flexibility of the joint should not be excessive, but there should be enough to allow the

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felts to adjust themselves closely to the lines of the strings.

An advantage is sometimes found in making the acting faces of bass dampers in three pieces, two of wedge or clip, and one of very soft flat felt. It is necessary sometimes to use double wedge felt for the lower trichord notes.

The pressure of the damper springs should be carefully graded: it sometimes needs to be rather heavy for the bottom notes.

The number of dampers is important; it is annoying to both players and hearers when certain notes force themselves upon notice by continued vibration. The number ought never to be less than 70 in either upright or grand pianos, and with scaling such as is herein advised, if the number be extended to 74 the result will be more satisfactory.

Damper spoons should be so regulated that they do not commence to move the damper arms at the same moment as the set-off buttons come in contact with the jacks, as, if these are coincident, there is a sudden increase in the weight of the touch.

In both grand and upright pianos the amount of "set-off" allowed is usually much more than is necessary for safety, for the risk of blocking upon the fly is exceedingly small in modern actions. The hammer travel being about 2 in., if the set-off is $\frac{1}{8}$ in. there is a loss of $6\frac{1}{2}$ per cent in the force of the blow. My own practice for many years has been to give a set-off of about $\frac{1}{16}$ in. in upright pianos and even a little less in grands.

Blocking on the check happens far more frequently, and it is wise to make some allowance, in checking, for an increase in the thickness of the check felt when the instrument is exposed to conditions colder and more moist than those of the factory.

The working out of the leverage proportions for pedal action is a very simple affair.

Set out lines as shown (Fig. 18).

Let line A be the measured length of a damper

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pedal rocker, and B that of the pedal itself, with the place of its connection with the rocker under the end of A.

Let *a* be the centre of the motion of the pedal. Decide the depth to which the end of B shall be depressed and mark that depth underneath. Draw a line between that mark and the centre of motion (see dotted line).

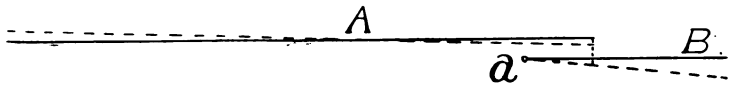

FIG. 18.

Measure the extent of the movement just under the end of A: this gives the first proportion for the rocker.

Now ascertain to what height the damper pedal stick has to rise, and you have the ratio for the lengths of the rocker on either side of its fulcrum.

Any one of the methods given for finding the fulcrum point for a key will suffice to determine it for a rocker, or for a roller movement. It is wise to allow a little for spring in this class of work.

The method of producing "piano" effects by means of a reduction of the force of the blows of the hammers is that now in favour.

The plan of sliding the hammers so as to strike on fewer strings, which still seems compulsory in grands, was at one time the only way thought of.

It is objectionable as causing unequal wear on hammer coverings and centres, and involves a heavy pedal action.

The pattern known as "Celeste" is objected to by musicians, as producing not only "piano" effects, but also another quality of tone, and, moreover, the soft felt slip wears away very rapidly.

When used in pianos with overdampers the slip is seriously in the way of the tuner and often damaged by his wedges.

The only valid objection to the half-blow pattern is, that it raises the notches of the hammer butts from

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contact with the flies, and causes a feeling of looseness during the early part of the key's movement.

Some years since a patent was granted for a mechanism by which this feeling was prevented.

The arrangement was most ingenious, but a little complicated, and seemed somewhat liable to derangement and rapid wear. As far as known it has not been used in this country.

The instrument with this device seen by the writer was made in America.

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CHAPTER IX

TUNING AND TUNING APPLIANCES

To deal fully with the subject of temperament would require several volumes of the size of this work, and were the tuner to make himself fully conversant with the arithmetic of his business, he would be really no more competent, *as a tuner*, than he may become, by constant practice, while quite ignorant. I have known many very capable tuners who had no knowledge whatever of the scientific basis of their profession.

Therefore a full elucidation of a very complicated subject will not be attempted, but only as much rudimentary knowledge offered as will be easily assimilated, and real students are referred to the many learned works which can be found in the libraries.

The young tuner is usually surprised when, among his first instructions, he is informed that only unisons and octaves are to be tuned to perfect concord, all other intervals in the scale of keyed instruments being more or less imperfect.

Attempts to remedy this have of necessity involved an immense increase in the number of notes for which keys and other mechanism have to be provided, and each of which has to be tuned to special relations with other particular notes.

This increase, affecting as it does not only makers and tuners, but also players, who are required to use a keyboard so complex as to demand a special education, makes it unlikely that any such modification of the present system can be generally acceptable,

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particularly considering the small gain which can be secured.

Very vague notions prevail among tuners, some of whom seem to believe that the need for tempered intervals arises from a gross plus error, contained within the limits of the octave, which, as it is not provided for by another key, must, by the flattening of a series of fifths and fourths, be distributed, in quantities so small as to be tolerable.

Those who content themselves with this as an explanation, have surely never reversed the ordinary tuning process, or it must have occurred to them that their plus error in the first case, becomes a minus one in the second, seeing that a series of sharpened intervals *in reversed order* brings them to the same result.

A few of the salient facts may be briefly mentioned.

First. A series of twelve concordant fifths, tuned within the limits of one octave, in the ratio of $\frac{3}{2}$, which is the true one, results in a note which is sensibly too sharp to form a perfect octave with the note started from, being in the ratio of as 531 : 524, an error of about $1\frac{1}{2}$ per cent.

Second. A succession of three major thirds, tuned to the ratio of $\frac{5}{4}$, results in a note which is flatter than an octave with that started from, in the ratio of as 125 : 128, an error of rather more than 2 per cent.

Third. A succession of four minor thirds, tuned to the ratio of $\frac{6}{5}$, produces a note too sharp to form a perfect octave with that started from, in the ratio of as 648 : 625, an error equal to about $3\frac{1}{2}$ per cent.

Fourth. Even what is called the natural scale (the diatonic succession) involves one error.

The ratios of that scale are usually expressed in the following numbers:

C	D	E	F	G	A	B	C
240	270	300	320	360	400	450	480

In the one octave there are four fifths, and to be quite free from defect they should each be in the ratio of as 240 : 360.

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Three of them are in this ratio, but that composed of the second and the sixth does not conform to the rule, being in the ratio of as 270 : 405 instead of as 270 : 400.

Fifth. The relation in which a sharp or a flat naturally stands to the note, the name of which it bears, is not equidistant between that note and the one next above or below.

G♯ is nearer to G than A♭ is; indeed, the frequencies divide the difference by 3, so that G♯ is one-third of the distance which separates G from A, and A♭ is also one-third of the distance which separates A from G.

In the tempered scale each semitone is equidistant from the notes above and below it; indeed, the whole set of discrepancies is reduced to order by a division of the octave into twelve proportioned steps, the frequencies of which stand to each other in the ratio of as 33 : 35,[1] the last of the series being the beginning of another.

This is true of every such succession, whatever note may commence it.

In the result the fifths counted upwards are a trace flatter than perfect, the fourths downward ditto, major thirds upwards are sharpened a good deal, and minor thirds upwards are very sensibly flattened.

The arithmetical amount of these differences varies with the frequencies of the notes composing the intervals, in the proportion of those frequencies, so that the differences are doubled or halved for each octave ascending or descending.

The reason why this is not readily perceived is that the *ratios* are not altered, and it is these which the ear accepts.

We have really no more acute sense of the discrepancies in the higher parts of the compass than in the lower, although the arithmetical differences are many times greater.

The beats (those variations of intensity by which

[1] An approximate simple ratio.

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small divergencies from pure concords become apparent) are due to a universal mechanical law that "opposed forces tend to neutralize each other, and that forces acting together intensify the effect of either."

If sound waves are projected from two sound sources, and if the frequencies are nearly the same, or nearly in a concordant ratio, when a condensation from one overtakes and coalesces with a rarefaction from the other, a moment of silence ensues, and correspondingly when condensation overtakes condensation there is a reinforcement of power.

These variations of intensity, *by their rate*, inform us of the amount of the deviation from unison or concord between the sound sources, the rate varies as the difference.

So that were a string tuned to, say, 300 vibrations per second, and another adjacent tuned to 299 or 301, there would be one beat per second registering the fact to our consciousness.

The rate of the beats does not inform us which is the higher of the sounds thus conflicting; this has to be otherwise ascertained.

The position in the instrument most convenient for what is called "laying the bearings" is around middle C, extending from F below to E or F above, and the intervals which are usually chosen for earliest adjustment are fifths and fourths, principally because of the slowness of the beats produced by the tempering of these intervals.

The practice of detecting errors by an appeal to other intervals is an economical, yea a necessary one.

An appeal to major thirds and sixths as they are reached in succession, shows whether mistakes are accumulating, and whether the fifths and fourths are flattened too much or too little. Some tuners make these more rapid beating intervals their first and chief dependence, and tune them directly, instead of using them merely as tests.

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As to the *rates* of the beats in intervals properly tempered, we cannot hope for a better authority than Helmholtz, who says: "Suppose we take the number of vibrations per second of C to be 264, the tempered fifth above will produce 9 beats in 10 seconds. The major third C to E will beat 10½ times in 1 second, and the minor third E to G, 18 in 1 second."

From this determination, which was undoubtedly made with extreme care, and with the aid of the best possible scientific appliances, it is easy to calculate the beat rates of such of the same intervals as are included in the scale used by the tuner.

The five included fifths and their beat rates are :—

Approximately	A	to	E	7·60	in 10 seconds
,,	G♯	,,	D♯	7·15	,,
,,	G	,,	D	6·75	,,
,,	F♯	,,	C♯	6·37	,,
,,	F	,,	C	6·00	,,

The average of the five equals 6·774 in 10 seconds, or 0·6774 in 1 second.

The major thirds, of which there are eight included, beat at the following rates :—

Approximately	C	to	E	10·50	in 1 second
,,	B	,,	D♯	9·90	,,
,,	A♯	,,	D	9·35	,,
,,	A	,,	C♯	8·85	,,
,,	G♯	,,	C	8·35	,,
,,	G	,,	B	7·87	,,
,,	F♯	,,	A♯	7·44	,,
,,	F	,,	A	7·02	,,

The average of the eight equals 8·66 per second.

The beat rates of the seven fourths, calculated on the same pitch basis, are—

Approximately	B	to	E	11·25	in 10 seconds
,,	A♯	,,	D♯	10·61	,,
,,	A	,,	D	10·01	,,
,,	G♯	,,	C♯	9·45	,,
,,	G	,,	C	8·91	,,
,,	F♯	,,	B	8·40	,,
,,	F	,,	A	7·93	,,

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the average for the seven being 9·509 in 10 seconds.

It will be readily recognized that $6\frac{3}{4}$ in 10 seconds is far too slow to be accurately counted except by the aid of special appliances, while the rate of the major thirds, which is $12\frac{3}{4}$ times as rapid, is by its extreme speed equally difficult.

To count beats against seconds in practical tuning is futile.

By long and constant practice the tuner acquires a sense of the required speed without counting.

With a view to decide whether the writer could use a "metronome," he once made a long adjustable pendulum, and found after extended trial that a trained sense of speed was a more dependable standard.

The present short tuning scale is of comparatively modern introduction.

Apparently to avoid the slight difficulty consequent upon the difference in the beat rates of adjacent fourths and fifths, the former intervals were not in olden times adjusted directly, but a fourth below was always tuned as an octave from the fifth above.

This had the effect of extending the bearings from pitch C to the F below middle C.

The system of temperament, by which some of the more used keys were favoured at the expense of others, had not long given place to the present plan when the writer had his first experience as a tuner, and there were still some middle-aged and elderly men, who were not able to adjust their minds and working habits to the new demands, and to whom the location of the "wolf" was a serious matter.

Presumably equal temperament is permanent, until such time, if ever, as improved mechanism shall make "just intonation" possible.

The scientists who apply tests which cannot be used in practical work, are somewhat contemptuous of our efforts. One of them, writing on equal temperament, says, "Practically, keyboard instruments

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are tuned only very roughly to this scale." This is probably true; but if the approach which can be made to the correct division is so near as to satisfy the most highly trained ears, a small degree of satisfaction may surely be cherished, mingled with an earnest desire for still higher attainment.

Pitch.

There are four pitches still used as standards in this country, of which the frequencies for C No. 52 are given in ascending order minus fractions:—

The French normal 517, which seems to be used exclusively on the Continent.

The new Philharmonic Society's pitch, 522. This is a concession made to meet the rise of pitch in wind instruments, particularly organs, which takes place in heated concert-rooms, and which pianos do not follow, their tendency being the other way.

Apart from this intention, it is difficult to see why there should be two standards so nearly alike.

The Medium Pitch, 530, a close approximation to the old Society of Arts pitch.

This is a convenient trade standard, which provides for a fall during the first few months of the life of a piano, and yet allows it to be at, or a little above, the lower ones. In a properly constructed, iron-framed instrument, this fall should be very small, if indeed it takes place in any degree.

The elasticity of modern wire, and the compensating action of an iron frame, carefully designed and positioned, should prevent it occurring in any appreciable degree.

The old Philharmonic pitch, 540, lingers, because there are wind instruments, etc., still extant which were made to that pitch and cannot easily be altered. So for the present the travelling tuner needs to be provided with a standard for each.

The actual frequencies of the Medium and

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old Philharmonic standards, seem also to be slight concessions to the conditions under which pianofortes are used in combination with wind instruments at high temperatures, the original numbers having been 528 and 538 respectively.

Tuning Appliances.

By this is intended those means which are provided for the adjustment of the tension of the strings.

For over a century efforts have been made to supersede the ordinary wrest pin driven into a wooden wrest plank, and numerous are the specifications which have been lodged with the Patent Office of inventions intended to make the tuning operation more delicate and the adjustments more stable.

Plainly some of them, in particular those which are intended to affect more than one string at a time, must have been designed by men altogether without personal experience as tuners.

Two main ideas can be observed as running through the whole series.

One to provide a direct bolt-and-nut action in place of the twisting action of the wrest pin (from which twisting action the name is derived), and the other to make the wrest pin itself more efficient as against the strains to which it is subject, wholly or partly setting it in metal, instead of in an unassisted wooden wrest plank. The first-mentioned plan has proved in every instance a failure, in spite of ingenious devices.

The expensiveness of them all would have prevented general acceptance, however efficient they might have been, but additionally, tuners found them much more difficult to manage, and the results of their work much less stable.

Every attempt along this line to supplant the ordinary means is foredoomed to failure.

The other main purpose evidenced has been to

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render the wrest pin itself more capable of resisting the strains, both direct and torsional, to which it is subject. Some of these endeavours have aimed at the exclusion of a wooden wrest plank entirely, and fixing wrest pins in an iron plate of sufficient thickness, either directly or into inserted plugs of wood or other similar material.

Of the first class, which required specially made and fitted pins, it may be said their cost has been prohibitive, and as a note of caution it may be pointed out that wrest pins, in *all-round* contact with iron, have been known to become immovable by reason of the surfaces being rusted together.

The other plan, which used ordinary wrest pins socketed in wooden plugs, is by no means so costly, and has been largely and fairly successfully used. There may yet be a general movement in its favour, and as a consequence the time-honoured wrest plank become a thing of the past. One of the chief difficulties in connection with this plan is to secure that the outside of the plug shall adhere so tightly to the hole in the iron, that it does not move with the pin.

The present aim is manifestly to supplement the wooden wrest plank with devices to counteract its defects.

The main defects are, a liability to split, a liability to shrink or swell with changes in climatic conditions, and a tendency for the wood to crush on the underside of the wrest-pin holes. All these defects are much ameliorated by the modern system of crossing the main plank with a substantial thickness of quartered beech, or in some cases by building up the whole thickness in reversed laminations.

When either of these plans is used, the liability to splitting may be regarded as eliminated, although planks do sometimes split behind a facing, and therefore the care in selecting those which are cut radially from the log should not be relaxed.

The difficulty due to contractions and expansions, according to hygrometric conditions, is thus largely

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removed also, and when the face of the wrest plank is further covered with a plank plate may be disregarded.

At one time the defect was serious, and was made very manifest in the practice of one maker who, to reduce the risk of splitting, used to place his wrest pins in rows much more widely separated than usual, overlooking the fact that the effect of face movements of the plank upon the tuning was thereby increased.

Even to one used to handling sensitive instruments these were abnormally troublesome. In cold, damp weather the strings attached to the upper rows of pins were very much sharpened, and correspondingly flattened when the heat of summer again reduced the width of the plank.

Cast-in wrest plank plates, while in some respects so valuable, are in one a cause of defect.

In the chapter on "Pattern Making" $\frac{3}{16}$ in. is given as the limit of thickness for this plate in the pattern itself. When cast it will be found to have increased to at least $\frac{7}{32}$ in.

It is usual for the distance between the visible plank face, and the string as it leaves the pin, to be nearly $\frac{1}{8}$ in., although there is no reason why this should not be reduced very sensibly.

This means that in such a case as we are considering there is nearly $\frac{3}{8}$ in. of pin unsupported and exposed to a very heavy bending strain, as well as a rather severe torsional one.

In one make of piano known to me, this defect is even greater, the distance being quite $\frac{1}{2}$ in., and this would cause serious concern were it visible, but it is hidden by the very thick plate. The crushing strain on the wood against which the pin presses is enormous in such a case.

Wrest pins may not *fit* holes in metal plates. If they even lightly touch the metal *while being driven* the roughing is marred, and the grip in the wood correspondingly reduced.

There is, however, no reason why they should not

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be so nearly a fit, that when, under the strain of the strings, the frame pulls up a trace, and the pins pull down a little, they touch upon the underside of the holes. It is admitted that it is not easy, under usual working conditions, to ensure that the holes in the wooden plank shall be so accurately marked and drilled, as to secure this advantage, but it can be done. There must be no japan left in the holes.

One method noticed in frames machined in America is an admirable one. The wrest-pin holes are deeply countersunk *from the back of the plate*, leaving only a thin edge of iron.

This renders it much easier to drill the inclined holes in the wood and drive the pins without damaging the threading.

Even if contact with the iron be secured it does not eliminate a last trouble. It does support the pin against the bending strain, and relieves the underside of the hole in the wood from undue pressure, but it leaves the torsion of the pin itself unaffected. The torsional spring of the pin, which takes place principally between the string and the point at which the wood grasps it, is considerable, and is distinctly felt by the tuner, who should in every case see to it that this strain is reversed, by a very slight backward touch of the tuning hammer, and one or two somewhat heavy blows upon the string being tuned. If he does not, the reversing will be more slowly done by the pin itself, with a consequent flattening of the pitch of the string. This is the operation sometimes called "setting the pin."

This particular trouble is at its minimum when there is not a metal plank face, or when a plugged iron wrest plank is used, because in these, the pin is gripped as nearly as it can be to the place where the string is attached.

A compromise which has been for a long time in use in other countries, and which unites all the advantages of the other systems, is beginning to receive notice from some English makers.

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The plank plates can be thicker than usual, although this is not necessary, but gives satisfaction to the ironfounder; and the holes, drilled out about 10·5 mm. diameter, are fitted with maple plugs made to drive very tightly, and usually recessed a little into the plank behind. If properly fitted no cement of any sort is needed.

The supply houses in the United States stock these plugs in various lengths and outside diameters, and with central holes either of the gauge required to fit the pin, or only large enough to centre a drill to bore both plug and plank together. The latter is the better pattern.

The recessing operation, the depth being gauged from the face of the plate, compensates for inequalities in its thickness.

Properly carried out this leaves nothing to be desired and, additionally, unites the whole structure in a homogeneous resistance to the strain of the strings.

Some critics even think it produces an improvement in tone.

The plugs are not expensive, and were there a demand, some supply house would soon either import or manufacture them, and it would not be long ere they would be universally used.

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CHAPTER X

STRAIN-RESISTING STRUCTURES

ALTHOUGH the strains in the early pianofortes were very slight, great difficulty was experienced in providing a structure to resist them.

This difficulty did not arise so much from the weakness of the materials used, as from the position relatively to the line of the strain in which the designs of the ancient grands and squares obliged them to be placed.

Considered as strain-bearers, the structures made prior to, say, 1800 were ridiculous, and even apart from the low elasticity of the wire used for strings, was a sufficient reason for the fact that in those days tuning always involved a raising of pitch.

There were no intermediate struts anywhere near the line of the strain, between the wrest plank and the piece of wood in which the hitch pins were placed.

True, in grand pianos some thin iron bars were later placed between the edge of the wrest plank and the face of the belly rail, but the effect of these was inconsiderable, because the belly rail itself was too weak, at the place of attachment, to offer resistance of any value.

With the increase of tension rendered possible by the increase of the tenacity of the steel wire, it became absolutely necessary by the application of iron bars to relieve the wooden structures of an impossible load, and by the middle of the century grand pianos strengthened by iron struts extending

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from the wrest plank to the S plate were rendered fairly capable to bear a gross load of some 14 tons.

But even so, the connection of the bars with the wrest plank was weak, as was evidenced by the crushing of the wood which took place at the bearing points.

In upright pianos it was easy to place bracings much nearer to the line of the strain of the strings than was possible in the squares which they displaced in public favour, and also without that break in the continuity of them made necessary in grands by the position of the action.

But even in the days just prior to the introduction of the cast-iron frame, the method of construction which seemed the only one possible, placed the line of strain a matter of 4 in. from the centres of the bracings which had to endure it, causing them to have to act rather as girders than as columns, subjecting them to a very heavy bending force.

Many attempts were made to amend this defect and counteract the bending strain, sometimes by the addition of iron bars or tubes behind the sounding-board, sometimes by the use of tie bolts at the back of the bracings; but in spite of these expedients the resistance was always insufficient and the tuning very unstable.

The cast-iron frame makes it possible in upright pianos to place the bulk of the resistance nearly in the line of the stress.

Reasons connected with the height of the sound-board bridges prevent this being absolutely done in all parts, but every endeavour should be made to so dimension and position the bars, as to render the frame independent of the assistance of wooden bracings, leaving to them the task only of providing a seating for the wrest plank and sound-board, and a means of secure union with the case.

This specially desirable position has, however, to be relinquished in the construction of horizontal pianos in favour of an advantage which cannot be

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secured in uprights, because in these the bars have to stand in the space between the strings and the action, and their depth is limited to the room thus allowed.

This practically compels some cutting into the depth of the bridge to clear the bars, but in grands it can be, and is, avoided by placing the line of stress underneath deep and narrow bars, which are really inverted girders; the bars of upright pianos may, however, almost be regarded as columns.

In explaining why the bars in grand pianos are so deep relatively to their width, it is needful first to bring into view a rule which applies to all girders, and second, a fact peculiar to the material we are considering.

The rule is, "The strength of girders varies directly as their width, directly as the square of their depth, and inversely as their length."

We can for our present purpose disregard the length.

Let us suppose that we may use for the section of a bar; material equal to 1 sq. in.

We will think of this section as formed of two pieces each 1 in. × ½ in.

Whatever strain one of these pieces can carry, the other by its side can carry the same, and so the strain-resisting power of a bar 1 in. × 1 in. is just double that of 1 in. × ½ in. placed upon its edge.

But if we unite these pieces so as to form a bar or girder 2 in. × ½ in. and place it so that the load is carried upon its depth, the strain-bearing power is quadrupled.

Let 1 stand for the strain-bearing power of ½ in. × 1 in. upon edge, then 2 will express the strength of 1 in. × 1 in., and 4 that of ½ in. × 2 in.

The fact peculiar to the material is the great difference there is between the compressive and the tensional strength of cast iron.

As opposed to a direct crushing force, it is exceedingly strong, but as against a tensile strain comparatively weak.

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When engineers are adjusting the dimensions of cast-iron girders to the loads they are intended to carry, they compensate for this great difference by increase of the flanges on the edge which is subject to tension.

If flanges could be conveniently cast upon the top edges of the bars of grand pianos, the depth could be correspondingly reduced, but the difficulty of moulding such bars prevents this course being followed.

To put flanges on the bottom edges, where the material is in compression, is merely to add to the strength at a place where it is already in excess.

Just the reverse is true of the bars in the frames of upright pianos ; these are usually slightly in tension on their back edges, and therefore the addition of flanges, which converts them into T section columns, adds strength at the place where it is needed.

The increase of transverse strength in proportion to the decrease in length is not likely to be very seriously regarded by pianoforte makers. Artistic reasons alone would prevent a corresponding reduction in the depth of the bars in grand frames, as they grow shorter towards the treble end.

It is a pity, however, that more attention is not given to such questions as those just discussed.

Frames of upright pianos could be lighter, and their strength increased, were the bars made deeper and narrower, and particularly were they carried right through to the top, beyond the place where the strain is applied.

To secure the full strength value of a calculated redistribution of the material would involve that the bars, which on the treble side of the crossing stand in advance of the strings, should be vertical, or otherwise the space which their depth may occupy is limited by the room required by the lower ends of the damper arms. There is no advantage at all in making the strings to slant in a position so high in the compass as prevents this.

An average of the compressive and tensional

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strengths of cast iron as stated by various authorities is: resistance to compressive strain per sq. in. 49 tons, to tensional strain $7\frac{3}{4}$ tons.

The transverse strength is of course a compound of these.

In dealing with a material the strength values of which are so diverse, the tensional strength being less than one-sixth of its ability to resist a crushing force, it is important so to use it as to secure the advantage of the higher value.

Had only the compressive strength to be considered, and were it possible to convey the whole strain of the strings through the exact centre of a single column, that column, if of 1 sq. in. section, would much more than suffice, and reckoning it to be 4 ft. in length, would only weigh about 12 lbs.

The ironfounders endeavour, by a mixture of various irons, to increase the naturally low tensile strength of mere pig iron. Repeated meltings also contribute much to this result, and is one of the reasons why "scrap iron" is in such demand.

Their aim is a metal which shall be as tough as it can be, and yet soft enough to be easily drilled, &c., and this makes them unwilling to have much intricate or delicate ornament included in the pattern, because so tough an iron as is suitable for the frame itself, is not so fluid when melted, as is metal of lower tensional strength, and consequently does not fill the details of ornaments so easily.

If such are required they should be separately cast in more fluid iron, and screwed into position.

One of the most valuable qualities of cast iron, as seen from the point of view of the pianoforte maker, is that its movements, due to temperature variations, are practically coincident with those of cast steel; so that its use in the strain-resisting structure ensures a compensating action. If, due to a fall in temperature, the strings contract in their length, with a corresponding increase of tension and therefore a rise

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in pitch, the bars of the frame shorten also in the same degree, and *vice versa.*

This is a complete reversal of the tendencies involved in ancient construction, in which the strain-resisting structure moved in the opposite way to the movements of the strings.

As contributing to the resistance to tensional strain, a wooden back should be unnecessary, and many attempts have been made to eliminate it.

It, however, provides a most convenient mode of attachment for the wrest plank and sound-board, and those makers who were at one time enamoured of double structures of iron, have reverted to the more usual method of construction, on that account.

If relieved, as it should be, of all vertical and transverse strain, the strength is of little importance, but having to provide a seating for the sound-board, its outside components should be sufficiently stiff for this purpose.

It is, however, often subject to at least one rather severe strain—the forward pull of the strings at the upper part, as mentioned in the chapter on "Bearings, &c." The carrying of the bars of the iron frame right up to union with a head bar, throws the strain upon them, instead of upon the wooden back, but in all cases it is advisable that the bracings extend at their full strength to the very top.

This method of construction is also economical of material and labour.

If the forward inclination of the steel strings mentioned in Chapter VIII is to be secured, it is necessary that the bracings be reduced in thickness at the bottom, to the extent of the angle made by the bass strings with the others, which may be taken as about $\frac{7}{8}$ in. in 4 ft.

The sound-board cannot be too rigidly constrained at its edges; the pulsations which travel from the bridge outwards should not be allowed to escape, but should be forced to recoil from a rigid surrounding band. One of the reasons why the tone of modern

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grand pianos is so satisfactory is that, surrounding the sound-board and opposing the escape of vibrations is a dense obstacle of hard wood, composed of a heavy bent inner rim with a very solid outer case attached thereto, and even where this bent surround has to be interrupted, its place is taken by an equally heavy belly rail, which also is usually made of hard wood.

So solid and dense a surround cannot easily be provided in an upright piano, although many years ago eminent American piano makers were bending rims for these, in the same way as for grands.

It is, however, urged that the edges should be provided with the most dense and rigid foundation possible.

The bracings of modern grand pianos are also not subject to any strains due to the tension of the strings, and may be regarded as only maintaining the shape of the bent rims, and so contributing a little to their rigidity, but as they do serve this purpose they are of value.

The use of the modern continuous bent inner and case rims has revolutionized the whole system of building grands, which can now be treated in the earlier stages of manufacture in a way similar to uprights, being bellied and marked off prior to the attachment of the case. The accompanying photograph shows a grand back.

The making of the rims requires special and somewhat expensive bending appliances. To fully describe these is not within the scope of this work. The illustration opposite shows a well-equipped bending room.

Three methods of bending and glueing up rims are known to the writer, and he has used two of them.

In one, the layers of stuff are fully prepared, then steamed, and forced to shape in the bending buck, in which they remain for over 24 hours, when they are removed and set aside to dry.

When fully dry they are placed in a hot chamber and thoroughly warmed; one surface of each layer

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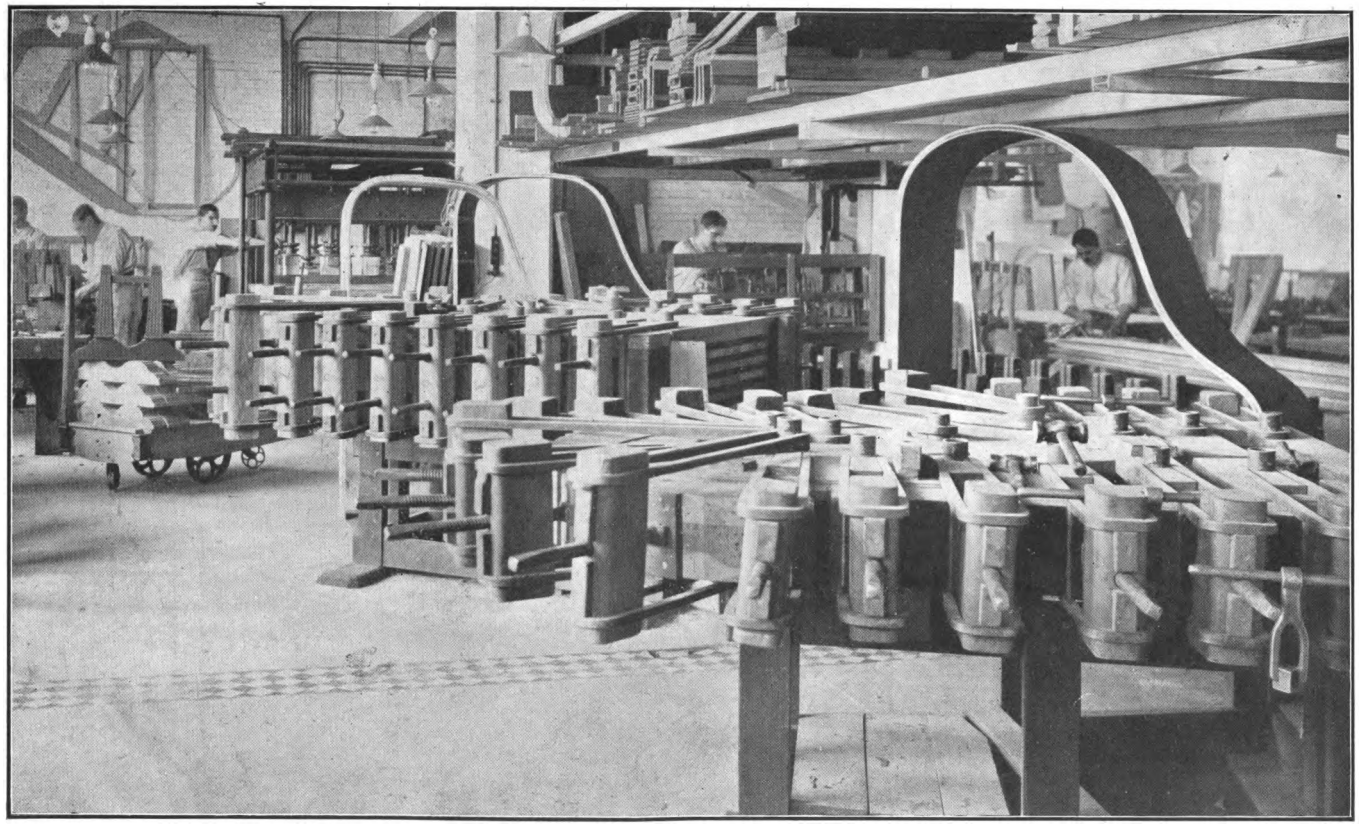

BENDING ROOM.

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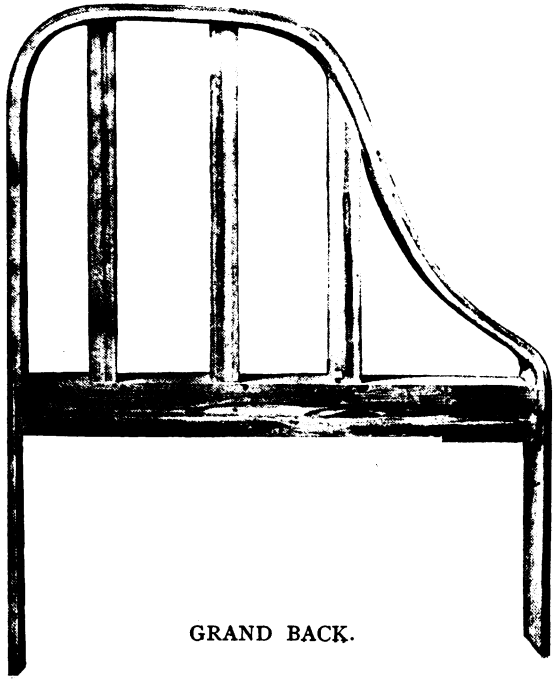

GRAND BACK.

IRON FRAME.

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is then coated with glue, and the whole reassembled in the proper order of the layers, and cramped up again in the buck.

When cold and the glue fully set, the outside and inside surfaces of the case rim are levelled, toothed, and veneered, the veneering also being done upon the buck.

No. 2 system differs from the above only in the one respect, that the veneers of case rims are laid at the same time as the rims are glued up.

When the above procedure is followed the layers of wood are usually about $\frac{3}{8}$ in. in thickness, and, except for those which are to be veneered, may be of American ash, sequoia, whitewood, or any mild wood fairly long in the grain; the two layers which are to be veneered upon should, however, be maple, and need not be more than $\frac{3}{16}$ in. in thickness.

It is not necessary, unless the case bends are very thin, that the direction of the grain of any layer should be reversed. Should, however, a layer be placed the other way of the grain, it is essential that it should be exactly midway of the thickness of the whole, in which case the number of the laminæ must be odd. The reason for caution is that if a reversed layer is nearer to one side than to the other, unequal shrinkage will sadly distort the case.

No. 3 system dispenses with steaming altogether, and each bending only occupies the buck once. It requires that the layers shall be thinner, as the wood is not softened by steaming. The process is, the layers are all dressed and toothed, and the inside and outside ones of the case are veneered while flat. Glueing up must take place within 24 hours of veneering.

All the unveneered layers are made hot through in a long oven, and each one receives a coat of glue, the next one being laid upon it, until all are in position, when the whole mass is lifted, placed in the buck, cramped up, and left till the next day.

This method, while a trifle more costly in wood and

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glue, is economical of time occupied in the bending machine, for a rim can be bent each day quite safely.

No time must be lost in glueing and bending; four men accustomed to the work can easily accomplish it in 15 minutes from the time of commencing to glue to the final tightening of the cramps, and if the wood has been thoroughly heated the glue will still run.

Whatever system is used, one precaution must be observed: the wood must not be stretched in the hollow curve of the bent side.

Bending may begin either at one end or in the middle—the latter is preferable; but in any case the hollow curve must be cramped right home while the layers are free to slip upon one another.

This precaution observed, there is no difficulty. If large numbers are not required, say not more than three or four per week, it is an all-round economy to have only one bending buck, making two or three inner rims in one width and bending the cases upon this.

Of course the faces of the cramping blocks have to be adjusted to the double requirements by fitments, or in some cases two sets of blocks are used.

The inner rims are afterwards divided to the required widths.

Naturally the ease of bending is proportioned to the softness of the curves.

Nothing should be attempted, even under the most favourable conditions, on a smaller radius than about 4 in. measured from the inside surface.

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CHAPTER XI

HAMMER COVERING, TONING, ETC.

For many years the hammers of pianofortes have been coated with felt, and it does not seem probable that a more suitable material will be discovered.

The hairs of many animals can be felted.

The peculiarity which renders them capable of this close coherence is, that they are not smooth and regular, but covered with "imbrications," i.e. minute projections like scales, which, when the fat that is always present in living hairs is removed, causes them to entangle each other.

At one time there was in use on the Continent a hammer felt said to be made of rabbit fur, it was not quite white and looked loose and ragged. While the tone produced by hammers covered with this felt was mellow and pleasant, the appearance predicted rapid destruction by wear, and it seems to have long been discontinued.

The felt now used on good hammers consists exclusively of carefully selected sheep's wool of long staple and extreme elasticity, the most suitable being imported from Africa, Australia, and Eastern Europe.

These are mixed in proportions according to the result intended, and made to interlace by persistent hand labour and machine processes, so that the mass coheres without a trace of any sort of cement, and the sheets which when thus felted are thick and loose, are finally brought to the required density by pressure.

The weight of wool used in a sheet of felt suitable for modern machine hammer covering varies from,

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say, 7 to 16 lbs., the sheet measuring about 36 in. in width at the bass end and 37 in. in length, the thickness (which is proportioned to weight and hardness) varies from about ½ in. to 1½ in. at the bass end.

The gradation in thickness from the treble end of the sheet to the bass is not a quite regular one, such as would be formed by two straight lines meeting at a point, but the lines are slightly curved, giving greater thickness to the part which will be used to cover the hammers between, say, Nos. 45 and 70, with a proportionally rapid reduction towards the upper end, and great increase of density. The grading can be varied in manufacture to suit special requirements.

As made, the hardness of the sheet is equal in its thickness at any part of its area, so that either side of it can be placed so as to be the face of the hammer; but in putting the felt around the wooden centre the inner portion is caused to be in a state of great compression, while the outer skin is in tension, and considerably stretched.

Fig. 21 shows the shape of the bass end of the felt as prepared to be glued to the centre, and from it an idea may be gained of the strains to which the whole coat is subjected as it is forced into the cauls of the machine. If a needle is pushed from one side, through the felt of a well-covered bass hammer, at various places along a line between the point of the wooden centre and the outer surface, it will be found that the hardness decreases regularly as the distance from the wood increases.

This is only fully true in the above line. If the test is applied at some distance away from it, the differences in density are much smaller, and near the ends of the felt can hardly be discerned.

The need for a graded density (very early recognized by pianoforte makers) is thus far more efficiently met, than by the old system of covering with several coats of various degrees of hardness.

It is due to the way in which the highly elastic wool is consolidated in felt making, and its density

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upon the hammers graded as described above, that the toner can so vary the hardness as to ameliorate the tone defects and irregularities with which he has to deal.

It is the aim of the hammer coverer (by adjusting the pressure of the machine) to make the set throughout a trace harder than they should finally be, so that by a very slight softening a satisfactory tone may be produced, but unfortunately it often happens that the excess of hardness is very great.

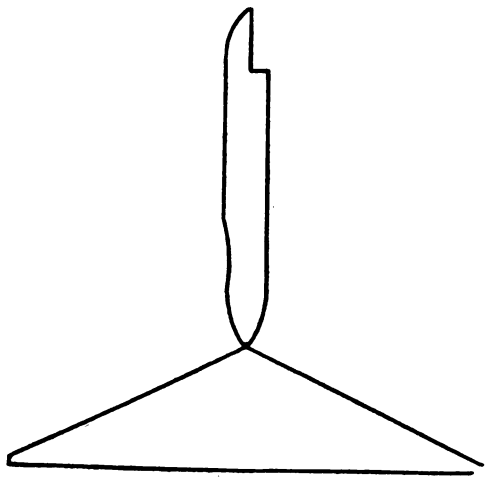

FIG. 21.

The less the toner has to do the more durable the result.

It is usually the outer skin of the felt which is affected in the toning operation, but it should not be exclusively so.

To specify just what ought to be done to produce a desired quality of tone is impossible, the treatment depends upon conditions which vary with every instrument.

There is no other part of the business of making pianofortes in which the risk of dissatisfaction, alike to operator and critic, is so great.

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A tuner can say whether or not a piano has been correctly tuned, it is either right or defective, but for the toner there is no such standard, and there are few subjects on which there are greater variations of taste and judgment.

There is a very common and misleading assumption, viz. that all tone defects and variations have their causes in the condition of the hammer felt, whereas they are very frequently located in other parts of the tone-producing mechanism.

Variations in the flexibility of the strings due to variations of the tension, or to irregularities in the striking position, will produce effects which seem to be caused by variations in the hardness of the hammers, and this error of judgment becomes confirmed when treatment of the felt has worked a total or partial cure.

But such a cure is only a temporary one, for notes of radically hard tone have been supplied with soft hammers which wear more rapidly than their fellows, and then the original tone defects again become apparent.

The above is written in support of the plea of the opening chapters, viz. that pianos should be so designed, and made—string tensions, flexibility, striking position, and all other details, so accurately graded —that supposing a set of hammers of perfectly equal hardness, the tone would be equal throughout the instrument.

The effect of such design and construction would be, that defects and irregularities of tone *would* have their causes in the hammers only, and the tone problem would be correspondingly simplified.

The production of the best quality of tone of which an instrument is capable, is largely a matter of instinct, trained by practice, and cannot be made a subject for precise instruction.

When piano tone is perfect, it does not change much in quality, but only in intensity (loudness), according as the blows struck upon the strings are light or heavy.

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It is quite easy to get (by mere shallow surface treatment) a pleasant quality of tone, if only light playing is the test. But, subject to the force exerted by many players, an instrument so treated may seem as though it had not been toned, the hard condition just underneath the surface becoming painfully apparent.

If the standard above laid down is to be attained, all surface softening *at the beginning of the toning process* should be avoided.

A satisfactory quality and regularity of tone *under heavy playing* should first be aimed at, and to accomplish this various means can be used.

There is one very highly renowned make of pianos, in which occasionally one sees that a portion of the felt has been removed from the upper and under edges of the hammers, thus relaxing undue strain, without affecting the elasticity at the actual striking face. However effective this method may be for its purpose, the obnoxious appearance induced will stand in the way of its general adoption.

Some toners attain the same result by a deep and close pricking in a radial direction, with a set of toning needles, around all the hammer except the striking face.

The writer prefers, in cases where the inside hardness is very great, to insert repeatedly a single long "glover's" needle (which is of triangular section), making it run in a line with the wooden centre, and almost in contact with it (see Fig. 22).

If a sufficient effect cannot be thus attained a similar series of perforations in the cross-direction is made, the object all through being to affect the interior condition.

This method is often very effective in dealing with hard short notes, due to slow transmission around places where the bridge has been deeply cut out to clear the iron bars.

Sometimes a combination of deep radial pricking with the above method is necessary to secure the intended result.

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When deep-seated troubles have all been dealt with, a very gentle surfacing with a group of fine needles will produce the condition suited to soft playing.

Either at the beginning of the toning process, or prior to the final surface treatment, the soiled skin of the felt, and the weak projecting edges, should be removed with fine glass-paper.

Hammers which are slightly rounding across their faces produce a better tone than when hollow, or even quite flat.

As to the reason why soft hammers produce soft tone, the usual explanation does not seem fully satisfactory.

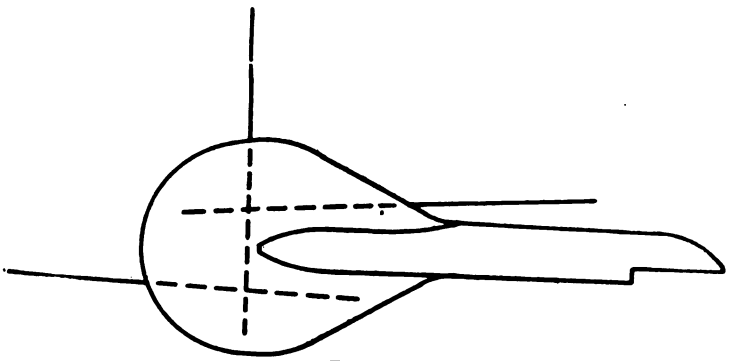

FIG. 22.

It is doubtless true that a soft surface indents more deeply, and therefore clings longer to the strings than does a hard one, and it is possible that high discordant overtones (if otherwise present) are thereby damped, but there are hard qualities of tone in which one does not detect any discord.

Sometimes hammers are too soft at the outset, or have been rendered so by over-vigorous pricking.

The only remedy in such cases, short of recovering, is to consolidate the felt by warmth and pressure.

This should be avoided if possible, as the tone produced by hammers so treated is never so satisfactory as it would have been had hardening not been

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required. The proper condition, which is a grading from firm interior, to softer surface, is reversed, and there is a hard skin with a softer layer behind it.

It frequently occurs that the felt of the hammers at the very top of the compass is too soft to render a sufficiently brilliant tone, and cannot be condensed enough by the use of the warm iron. An expedient by which this can be remedied is to moisten the points with either thin "white French polish" or a solution of celluloid, and when quite dry the slight discoloration is removed by a touch of glass-paper.

The effect is very satisfactory, but only for hammers between, say, Nos. 83 to 88.

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CHAPTER XII

SEASONING TIMBER

FEW subjects are of greater importance to the pianoforte maker than that of the removal (from the various woods which he uses) of the water with which they are originally charged, and with which they part so unwillingly.

Although trees are felled at the time when the sap is down, the timber contains on an average about half its weight of water, which must be reduced to a minimum prior to use, but can never be so thoroughly removed as to leave less than about 4 per cent remaining.

It is said that the timber work inside houses, always retains from 8 to 12 per cent. It is a current belief that the object of "seasoning" is the removal of something more than moisture, and it is certain that timber exposed to rain, or soaked in pools, does part with some soluble matters which the sap has held in solution during the life of the tree, but there is no real gain in their removal, and in any case the removal of these sap constituents can only be from the surfaces or from layers very near to them.

The seasoning operation is properly the removal of water only.

For the thought that the drying process should be very slow there is more reason, although even in this there lurks a fallacy.

The slowness of the drying is not *in itself* an advantage; the advantage lies in the fact that when, under natural conditions, the removal of the moisture

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is very gradual, the shrinkage is also gradual, the outsides are not hurriedly tightened upon the centres of the planks or logs, which, if permitted, results in the certain rupture of the surfaces in shakes.

But no merely natural seasoning can altogether avoid that compression due to the surfaces shrinking more and earlier than the interiors, nor can the drying be carried to a point at which less than about 10 to 20 per cent of water shall remain, even after very long exposure to the air, and even when the timber has been reduced to comparatively small dimensions.

Twelve-inch squares of hard woods have been known to contain over 20 per cent of water after six years' drying in a warmer climate than our own.

The usual and old established practice of piano makers is to complete the drying of their woods in the racks of the workshops, and there is no doubt that, when the bulk of the moisture has been removed by open-air seasoning, this system gives fairly satisfactory results.

The principal faults which can be alleged are, first, the plan is not economical, and second, it cannot carry the drying process to the highest possible degree.

The growing shortage of the sorts of timber used in the trade, and the consequent increase in the cost, make it important that every saving which can be made in usage should be secured.

The chief loss in connection with the old seasoning process, is in the time during which money invested in timber is lying unproductive.

Even if seasoned wood is purchased, this loss has to be made up in the price.

The second loss, is in the damage to outsides which perforce results from exposure, and which prevents most timber which is to be subject to such conditions being cut near to working dimensions prior to seasoning.

Both these causes of loss can be minimized if one of the artificial systems of drying can be adopted.

The principle upon which these systems work is to

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keep surfaces expanded during a period in which the moisture is being drawn from the interiors, and so, during the earlier stages the timber is kept moistened, as well as heated, in drying chambers or kilns, by the injection of steam.

When the whole bulk which is being treated, has been raised to a temperature which sets the water in the centres seeking an outlet, the injected moisture is gradually reduced and a rapid circulation of the air set up, until at last the surfaces are dried off, the last remaining moisture being driven out of the chamber.

This is just a reversal of the ordinary seasoning process: for drying and shrinking proceed from the centres to the exteriors.

The degree of economy which results from arrangements for such working depends, in part, upon whether there is heat being wasted, or a heating system not being worked to its full capacity. Granted either of these things, a drying plant can be easily installed and cheaply worked; but no factory which has not a central source of heat can have associated with it a drying kiln, except at considerable initial outlay and continuous cost in working.

Three things are required for the effective working of a drying-room.

First. Floor heat, fairly equally distributed over the whole area of the chamber and capable of being controlled.

Second. Some means of moistening the air with steam.

Third. Some way by which, during the latter half of the drying course, the air of the chamber may be kept in active circulation, and finally ejected, its place being constantly filled by the entrance of air from the outside, dried in some way, sometimes by passing over the pipes which supply the floor-heat.

When kilns are installed by the professional builders of such, the circulation and ejection depend upon the action of a fan, which requires driving power.

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The fan is often made to do more than this, and is associated with means for heating the incoming air to a degree a good deal above that of the floor-heat, and then the air, so heated, is driven through the interstices of the stacks of timber.

But a fan can move the air and finally eject it merely by the formation of a partial vacuum at the outlet, and in cases where a factory is without power of its own, can without large cost be driven by aid of the public electric supply, now almost everywhere available.

If, however, a flue connection can be made with a quick-draught chimney shaft, the fan can be dispensed with.

A small but very efficient kiln, designed by the writer, was merely a chamber contiguous to a shaft, with a series of steampipes placed near to a concrete floor, with two steam-taps to moisten the air, and with a few bricks removed from one wall here and there, at the lowest level, to admit air. The circulation and ejection were by means of a flue connection with the shaft. All the inlets and the outlet were regulated with valves. These were closed during the early part of the drying course, and gradually opened as the moisture was required to be dissipated.

The main defect of all drying systems which depend upon the factory boiler is that their working is discontinuous.

The loss is more than that of the mere time during which the heat is not being supplied.

When the whole stock has cooled down, as it does during each night, and more so during the time from the Saturday closing till the resumption of operations on Monday, it takes a good many hours more ere the temperature loss is made up again.

In drying-kilns where great quantities of timber are treated and the process is continuous, the time in which even newly felled and opened stuff can be completely desiccated is marvellously short.

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In some cases it is said to be accomplished in about 60 to 70 hours with 1-in. stuff.

But in these cases the temperature used is about 100° F. above that of the outside air, and is kept at that the whole time.

The time required for a drying course, depends upon the temperature used, the previous condition of the wood, and its dimensions. Therefore no absolute rule can be given, but a very little experience with a kiln will enable an intelligent person to work it effectively.

Soft woods dry more rapidly than hard, and small dimensions far more rapidly than large.

Naturally the time required for the drying of the hard timbers is longer than for soft in proportion of their density.

The weight of the material of which the various woods are composed does not vary much; the difference lies in the degree of their condensation.

The structure of pine wood is very loose and open, while that of such woods as oak and beech is much more closely compacted.

Comparing an average of the heavier fir-woods with those last named, shows a weight difference of 40 per cent, but if both are completely emptied of air, and the place thereof filled with water, the difference is reduced to under 5 per cent.

It is not commonly known that all timbers are (except for the contained air) heavier than water.

The shorter the timber the better; the easiest outlet for the moisture is through the ends of the pieces; indeed, the discharge at this part is sometimes rather too fast for the water in the interior to follow.

As regards the other dimensions, the time allowed must be *more* than *as* the thickness.

Thus, if 1-in. stuff were fully dried in one week, 2-in., if of the same material and condition, would require more than two weeks.

A very simple hygrometer, by which the condition of the wood can be judged by that of the air of the

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kiln, can be made by glueing together two pieces of thin wood, say 24 in. × 2 in. × $\frac{3}{16}$, one lengthwise of the grain, the other on the cross.

When exposed to moist air, the crosswise side will swell, and when dried again will shrink, and in a rough way will, by the curvature of the lath, indicate the condition of the air.

It can be fixed at one end, so that it points to an adjustable zero mark.

If the adjustment is made to the condition of the air in a warm, dry workshop, the instrument will (when placed in the drying-chamber) show by the direction and extent of the movement of the lath, the condition there, from which that of the timber can be inferred.

Of course, such an indicator must not be exposed to the wet air of the earlier part of the process.

Scientific hygrometers depend for their action upon the expansion and contraction of a single human hair. I have not found them so easy to use as the above.

When afterwards exposed to normal conditions, kiln-dried wood expands very slightly, which is not a disadvantage.

Pianos made of wood so treated are much safer if they are sent to hot climates.

It is essential in any artificial drying arrangement, that air entering the chamber shall not be able to find an easy and direct road to the outlet, but be compelled to circulate among the layers of the timber.

The easiest way to ascertain the progress of the drying is to weigh selected pieces at the outset, and at stages during the operation. When a condition is reached at which (some time after the injection of steam has been stopped) no further reduction of weight can be detected, it is safe to infer that the process has been carried as far as is necessary. The weights given in books on timber, are not for stuff so dry as the pianoforte maker needs, and are averages.

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Another thing which makes such information of little real use is the difficulty of measurement. The weights given are for the cubic foot, and it is by no means easy to measure the three dimensions of various and roughly-cut timber with the accuracy needed to determine whether it is heavier or lighter than the weight given in the table, so that on the whole the rule given above is the more practical.

If it is desired, however, to make an appeal to the tables given by the authorities, and only one of specific gravities is available, the weight per cubic foot can be ascertained by multiplying the specific gravity of the wood by 62·5, the weight of a cubic foot of water; thus, specific gravity of pine, $0{\cdot}55 \times 62{\cdot}5 = 34{\cdot}4$ lbs. per cubic foot approximately.

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CHAPTER XIII

GLUE AND ITS ECONOMICAL USAGE

LONG and careful watching has convinced me that the usual treatment of glue is very wasteful; not only in respect of the quantity expended upon the work, but also of its holding power.

That treatment is to keep the solution as near as is possible to the boiling temperature, and constantly remove the scum, which always rises when 160° F. has been exceeded.

The current belief is that the scum is composed of impurities, which have to be got rid of by boiling, instead of being valuable adhesive material, which has been separated, possibly by coagulation, due to the heat to which the solution has been subjected.

The tenacity with which this belief is held is very strange, seeing that every glue user knows that scum continues to form as long as the glue is kept hot enough.

This practice not only wastes the material, but brings the remaining solution into a condition in which it will not run freely from the brush, but seems as though heavily charged with resin. This renders it difficult to spread thinly, and also demands that (for veneering) the cauls shall be heated to correspond, as otherwise the surplus glue could not be pressed out, having been brought into an intractable condition.

The need thus produced for the extreme heat of cauls means a corresponding loss in fuel. Just how much damage is done to the holding-power of the glue cannot be easily expressed, but it is very con-

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siderable, and varies with the degree of the heat and the duration of the exposure. One authority on the subject of glue manufacture and usage says that it loses half a grade if kept at a temperature of 200° F. for one hour.

Recent researches show, that to secure the best results and greatest economy, the glue solution should not be heated, *in any stage*, above about 145° F., and that cauls should not be more than about 10° hotter.

Very careful experiment has proved that a solution containing about 60 per cent of solid glue will not jelly until it has been cooled to 75° F., which is really about the average temperature of a part-making shop, showing that there is no real danger of chilling.

The experiments which prove this were made with glue which had not been hotter than 155° F., and it is not asserted that the working temperatures herein given would be safe for a solution which had been previously overheated.

Better work can be made with thinner glue if these precautions are taken.

At least a 60 per cent solution is used by most workmen, but if made and used as above a 45 or 50 per cent mixture will not only save glue, but produce much better work, there being less glue in the joints: veneered surfaces are flatter, and the cauls not having needed to be so hot, the saturation of the veneer is less, the cleaning up is therefore easier.

In some of the great case-making works in the United States, the glue used, in proportion to the surfaces covered, is only about 50 per cent of that which is common in this country. Admittedly a part of this saving is due to the use of machine spreaders, which only put upon the work the amount of glue which is known to be necessary; these could not be economically installed in small factories but a careful attention to temperature of glue and cauls, and also to the thickness of the solution, will earn a corresponding reward.

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Naturally the percentage of the solid glue must vary with its quality—if of low gelatinizing power the solution must contain more, but pianoforte makers mostly use good and expensive glues.

In the great works above mentioned, they have a standard percentage, according to the ascertained quality of the glue, and the temperature (both in the boilers and in the spreading machines) is carefully watched, both heaters and retainers being fitted with thermometers.

It would be of advantage to glue users if manufacturers could supply the same in, say, ½ in. cubes.

The solution would then be so easy to make that the present temptation to overheat in cooking would be much reduced, and also only the quantity actually needed could be melted from time to time; it is clear that even repeated melting is very detrimental.

The affinity of gelatin (which is the principal constituent in glue) for water is its greatest defect, as judged from the point of view of the pianoforte maker, who has to send his work into all sorts of climates.

It is said that in some tropical regions, during the wet season a cake of glue left exposed on bench or desk will actually become a jelly, by mere absorption of water from the air assisted by the high temperature which prevails.

The addition of a very small quantity of bichromate of potash has the effect of rendering glue insoluble after it has been exposed to light, which however turns it black in time, and of course the light cannot penetrate deep joints.

It is said that by the addition of formalin the same result can be attained.

There is a real need for a new cement which shall have a tenacity equal to that of glue, which shall be used in a similar manner but which shall be free from that affinity for water which as aforesaid is the chief defect of glue.

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APPENDIX

OVERTONES or "upper partials," are those components of a sound, which are above the fundamental. When all the components including the fundamental are mentioned, they are called the "partials." Therefore in the scale of overtones on page 16, the fundamental is not numbered, whereas in the diagram, page 17, it is included as No. 1.

In treating of scale calculation, the aim of the writer has been to present a rather difficult subject in its simplest possible form.

The method of procedure advised, is one, which by the aid of the slide rule, *and treating each quantity as a whole*, can be easily and quickly accomplished, with an approach to accuracy as near as can be used in practical scale drafting.

As stated on page 30, this method is open to the objection that figures beyond the second or third, are only estimates, and liable to error, but such errors are really too minute to be considered.

The slide rule is mostly used to assist ordinary arithmetical processes, but in such cases the saving of time is not great, whereas, if each whole quantity is dealt with in a single reading, the economy is very large. In dealing with ratios such as 9 : 17 for octave lengths, and as 37 : 39 for semitone ditto, an easy way is, to set the lower number on one scale under the higher on the one above, and read from scale to scale successively. A widely separated ratio, like as 9 : 17 can only be read conveniently on the two upper lines of the rule, but such numbers as 37 : 39 are best dealt with on the two lower lines.

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Other octave ratios have been recommended, one as 8 : 15 another as 8 : 15·5. The former of these is a little too short to produce equality of tension on the basis of an increase in the thickness of the wire by one whole number per octave, the other is much too long.

To any who may wish to calculate string lengths by ordinary arithmetic, the following multipliers will be useful.

For octaves 1·89, and for semitones 1·0544. The octave multiplier to be used on four figures of each previous product and that for semitones on six figures.

A convenient way to reduce risk of error is to multiply the length of the top note of the octave × 1·3745, thus :

C 5·4 cm. × 1·3745 = 7·4223 cm. for F♯.

When the lengths for the top octave have all been ascertained, those for the lower ones are determined by successive multiplications × 1·89.

The ratios and multipliers as above, both work almost perfectly for nearly five octaves downward. Lower than this, a small minus length error begins to creep into measurable limits. This position is usually beyond the requirements, but in a scale for a concert grand piano, an adjustment can be made thus : bring down the constants of the octave above and, reversing the method of Table III, work back to the required lengths.

Re the use of square roots of sectional areas of wires, as multipliers, rather than diameters. Whichever is used the comparative results are the same, expressed in different figures. If, in the tables, diameters had been used, the figures of the constant would have been so near to those of the tension as to cause confusion. The only other ground of preference is, that the use of the diameter, obscures the fact that the area of the section of the wire, is less than the square of the diameter.

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In discussing, on page 91, the suitability of Swiss-pine as a material for soundboards, use is made of a calculation by the late Professor Tyndall, which fixes the rate of vibration, lengthwise of the grain in fir-wood, as 15,218 feet per second.

No information is given as to the kinds of firwood used, and I have assumed the "spruces," to which the Swiss pine belongs, to be included.

On page 118, on the subject of the relative lengths on either side of the fulcrum of a key, a proportion of as 9 : 5·5 is used. The most likely proportion for upright pianos is, as 3 : 2, and for grands, as 2 : 1, for balance and back lever respectively, but variations are frequent and considerable, although the above are regarded as standards. The as 9 : 5·5 proportion is chosen as a somewhat more difficult ratio than either, upon which to exhibit the method of calculation.

ERRATA.

On pages 11 and 12, Figs. 2 and 3, *for* "No. 20–22·3 cm." *read* No. 20–22·4 cm.

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